Life in the universe may be stranger than you think — page 28

April 2005
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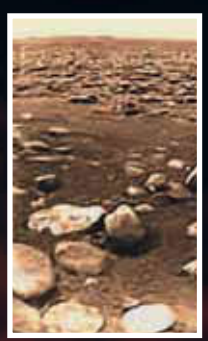

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Vol. 33 • Issue 4

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RCX400™

ADVANCED RITCHEY-CHRÉTIEN DESIGN

12" RCX400

Redesigned Meade Super Wedge (Optional Accessory)

On March 26, 2002, Meade engineers set out to design a telescope with optical performance superior to any sold today. It would feature the most sophisticated and technologically advanced mechanics and electronics ever offered. In short, it would be a professional observatory-level telescope for the serious astronomer and astrophotographer.

After carefully evaluating the merits of every telescope design, Meade engineers concluded the Ritchey-Chrétien was the optimal design. A fast (f/8) RC design produces a large, coma-free field of view from edge-to-edge, allowing astrophotographers to use the latest in imaging technology to capture tack sharp images over a wider field. Visual observers can view pinpoint stars and extended objects across the larger field of view. In fact, almost every professional reflector telescope in the world's observatories is a Ritchey-Chrétien, even the Hubble Space Telescope.

Although the Ritchey-Chrétien is the premier optical design, Meade engineers saw opportunities for further improvement. The RCX400 optical design consists of a hyperbolic secondary and corrector lens/primary combination that performs as one hyperbolic element. Further, by utilizing the precision polished and figured front corrector lens, the engineers were able to eliminate the typical secondary mirror support structure which causes diffraction spikes that degrade image contrast and resolution. The corrector lens also minimizes the astigmatism inherent in the traditional RC design. Performance was further improved by incorporating computer-optimized baffling and Meade's unsurpassed Ultra High Transmission Coatings (UHTC™) for maximum image contrast and brightness.

In the hands of the serious astronomer or astrophotographer the new Meade RCX400 is an instrument that will produce razor sharp star images across the entire field of view on par with the best professional observatories. The dream of owning the ultimate Advanced Ritchey-Chrétien telescope is finally here. Log on to Meade.com/RCX400 for more details. Delivery will be on a first-come basis. Book your RCX400 today from an authorized Meade dealer.

All RCX400 telescopes are made in the USA at Meade's state-of-the-art design and manufacturing facility in Irvine, California.

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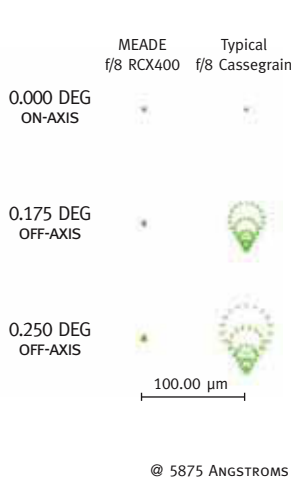
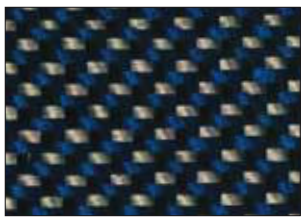
SPOT DIAGRAM

Note the extremely small, round star images — even at the edge of the field of view. Only the RC optical design can produce such on and off-axis performance. Before the new Meade RCX400 the serious astronomer would have to pay more than three times the cost to get a telescope that delivers this level of professional observatory optical performance.



MEADE RCX400 PRODUCT INNOVATIONS

MULTI-PORT CONTROL PANELS
The RCX400 is the first telescope to feature a powered, three port high-speed USB 2.0 hub. Separate control panels are positioned on both the drive base and rear cell of the OTA, allowing equipment such as AutoStar® II and the Deep Sky Imager™ to be plugged directly into the OTA control panel, preventing cord wrap.



CARBON FIBER & KEVLAR OPTICAL TUBE
This unique light-weight material produces superior strength with thermal characteristics ideal for long-exposure astrophotography. As the temperature rises or falls the RCX400's optical tube resists expanding, keeping the optics in focus.

LASER ALIGNED, FIXED PRIMARY MIRROR
The primary mirror is laser aligned to the true optical path, then float-bonded in place. It is fixed, but literally floats on a layer of adhesive that results in zero stress to the glass and no distortion to the optics (unlike mirror cells or floating point systems). There is no mirror movement.

ELECTRONIC FRONT FOCUSING SYSTEM
The patented RCX400 front focusing system produces a razor sharp focus. With its laser aligned primary mirror fixed in position, focusing is performed digitally (via the AutoStar controller) by using three encoder controlled motors to precisely move the entire front cell in increments as fine as 1/1000 of a millimeter.

BUILT-IN ANTI-DEW HEATER
A heating coil is affixed to the entire outside edge of the corrector lens. Because the corrector lens is receiving the heat directly, it uses a fraction of the energy of after market anti-dew heaters. The RCX400's dew heater has temperature sensors, and is adjusted via the AutoStar II Controller.

ELECTRONIC COLLIMATION
Most telescopes are not often collimated because the process can be difficult and time consuming. Now, with the RCX400's new computer-controlled collimation system you can precisely collimate the telescope in seconds using the AutoStar II Controller in a simple up-down/left-right movement.

INTERNAL ELECTRONICS & MECHANICS
The internal electronics and mechanics were designed from the ground up. For example, the RCX400 features balanced worm blocks that allow the motors to deliver the same load no matter the orientation of the OTA in RA or DEC. Fork arms, are both longer and stronger. This allows the 10", 12" and 14" scopes to go all the way to -90 degrees declination on a wedge, allowing you to reach the horizon. The increased fork size also gives more back clearance to allow imaging all the way to the pole with most cameras. The inclusion of an OTA fan accelerates cool down time resulting in faster optical equilibrium with the ambient temperature.

9 FOCUS POSITION PRESETS
By setting up to 9 focus positions you can customize perfect focus from eyepiece to eyepiece and from a visual setup to a camera setup. You can also customize perfect focus from observer to observer with different eyesight (similar to the custom settings in luxury cars to change the seat settings from one driver to another).

COMPUTER-OPTIMIZED BAFFLING
Baffles on the primary and secondary mirror are computer-optimized to provide high contrast images. The RCX400's baffles prevent stray light rays from reaching the focal plane.

NEW RCX400 ULTRA-STABLE TRIPOD
This innovative new tripod was designed and engineered to provide the serious astrophotographer rock solid stability. The entire tripod is machined from aircraft-grade 6061-T6 aluminum. It features patented trigger release leg locks making height adjustments quick and easy. The tripod can be assembled and disassembled in seconds, making it the most solid, hassle-free and ultra-portable tripod on the market.

OPTICAL DESIGN	ADVANCED RITCHEY-CHRÉTIEN DESIGN			
Aperture	10"	12"	14"	16"
Focal Length	2032mm	2438mm	2845mm	3251mm
Focal Ratio	f/8	f/8	f/8	f/8
Series 5000™ Eyepiece	24mmUWA	24mmUWA	24mmUWA	24mmUWA
UHTC™	Included	Included	Included	Included
Price	$4,999	$6,599	$8,999	$15,999
Shipping & Handling	$145	$215	$265	$385

KEY FEATURES
- GPS & Level-North Alignment System
- Upgraded AutoStar II Controller
- Cooling Fan
- Smart Mount™
- Smart Drive™ (Permanent Periodic Error Correction)
- Oversized Primary Mirror
- 24mm Series 5000 Ultra Wide Angle Eyepiece
- Ultra High Transmission Coatings (UHTC)

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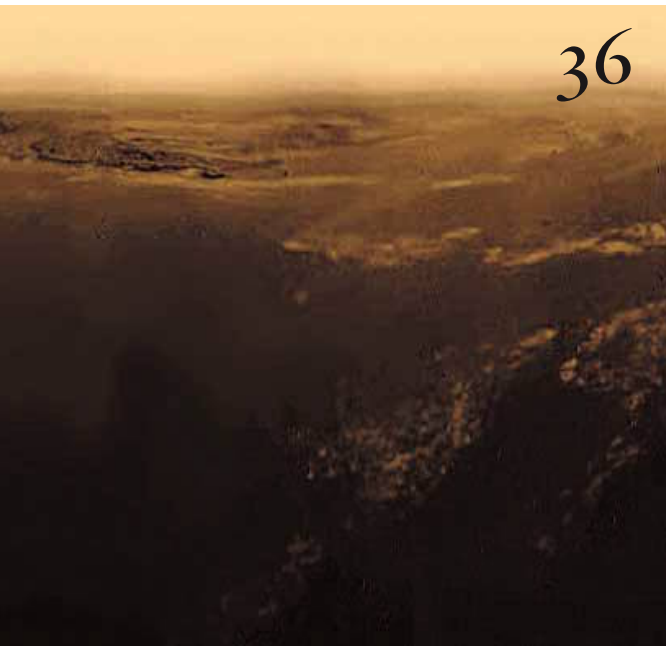
features



ESA/NASA/UNIVERSITY OF ARIZONA

JASON WARE

ASTROBIOLOGY

28 Quest for a living universe

How do you search for extraterrestrial life when you don't know what it will look like? Some conditions for life may be universal, but the telltale signs of life's existence may not be that obvious. ALAN LONGSTAFF

COVER STORY

36 Titan touchdown

The Huygens probe plunged into the atmosphere of Saturn's moon Titan, showing Titan is a complex world with an intriguing landscape and possible flowing liquids. RICHARD TALCOTT

EXTRAGALACTIC ASTRONOMY

42 Darker than the night

Astronomers are scrambling to figure out galaxies that produce so few stars, and glow so dimly, they nearly disappear into the night sky. Amazingly, these oddballs could outnumber "normal" galaxies ten to one. BRUCE DORMINEY

EXTRAGALACTIC ASTRONOMY

58 Seeking the first galaxies

The Hubble Space Telescope's million-second stare into space is our deepest look at the universe, but astronomers disagree over what it shows. Some argue it includes the earliest galaxies. FRANK SIETZEN, JR.

ASTROPHOTOGRAPHY

64 Sharper photos with film

Reports of the death of film for astrophotography are exaggerated, so don't sell your single-lens reflex camera yet. Digital technology can help you create high-quality celestial images caught on film. JASON WARE

EQUIPMENT REVIEW

70 Binoculars under $100

Sometimes, observing is best with both eyes open. Binoculars are a great first step into astronomy — learn how to choose a model that's right for you at a price you can't resist. PHIL HARRINGTON

Includes an on-line extra available only to *Astronomy* readers (see page 5 for details).

JOHN R. FOSTER

48

departments

06 This month in *Astronomy*
Is anyone out there?

12 Letters

14 Bob Berman's strange universe
Major Ursa phobia

16 Glenn Chaple's observing basics
Gemini secrets

18 News
- Infant stars in the Small Magellanic Cloud
- Dusty debris at Vega
- Big Bang sound waves made galaxies cluster
- Have martian volcanoes erupted recently?
- Black holes crowd the galactic center

48 The sky this month
A solar eclipse rarity
MARTIN RATCLIFFE and ALISTER LING

62 Ask Astro
Gravity's speed, gravity's lens, Mars mikes

78 New products
- Meade's Deep Sky Imager
- Denkmeier's Binoviewer
- Denkmeier's 2" SCT diagonal
- Agena's solar filters

80 Resources

84 Coming events

85 Advertiser index

93 Reader gallery

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ON-LINE EXTRAS THIS MONTH:

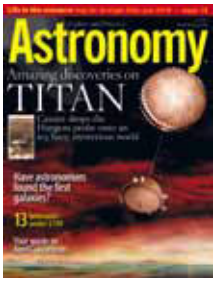
QUEST FOR A LIVING UNIVERSE: Explore the world of ancient microfossils — the remains of Earth's first life-forms.

TITAN TOUCHDOWN: See the latest pictures returned from Cassini/Huygens.

DARKER THAN THE NIGHT: Learn which Local Group members are LSB galaxies, and try your hand at finding some.

SEEKING THE FIRST GALAXIES: Steven Beckwith, STScI director, discusses with *Astronomy* the Hubble Ultra Deep Field and the telescope's fate.

SHARPER PHOTOS WITH FILM: Enjoy a gallery of Jason Ware's dazzling astrophotos.



ON THE COVER
On January 14, the European Space Agency's Huygens probe landed with a "splat" on the surface of Saturn's moon Titan. The robotic spacecraft's descent and landing energized scientists in their quest to understand the ringed planet's biggest moon.

ESA; SATURN: NASA; INSET: ESA/NASA/UNIVERSITY OF ARIZONA

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BY DAVID J. EICHER

Is anyone out there?

The odds seem staggering. As many as 200 billion stars float majestically around the Milky Way's center. At least 125 billion galaxies make up the visible universe — and, if inflation theory is correct, that might not equal anywhere near the total number of galaxies because we can't see the whole thing. These numbers suggest a universe

teeming with 25 thousand billion billion stars. And we know of just one star with one planet that has life. Is it possible the rest of those trillions of stars, many of which should have planets, have no signs of life?

There's a bigger question, however. Even if the universe is teeming with life, as Carl Sagan proposed, how would we recognize it if we saw it? Will we find planetary surfaces etched with organisms or relics from civilizations past?

"Chances are the evidence will be much more subtle," writes astrobiologist Alan Longstaff, a staff astronomer at the Royal Observatory, Greenwich, outside London.

In his story "Quest for a living universe" (starting on page 28), Longstaff suggests the evidence may indeed consist of "tantalizing spectral lines of biomolecules in the light from a distant earthlike world, or structures within rocks from another planet that are not of obvious geological (or even biological) origin."

What we do know about life comes from one sample: Earth. Life here replicates itself and evolves over time. It uses energy, needs water, and is carbon-based. It exists in some hellish places where it seems nothing at all could live.

In the deep dark of the oceans, for example, hyperthermophiles flourish. These organisms thrive in high-pressure saltwater without sunlight or oxygen and at temperatures up to 242° F (117° C). Hydrothermal "black smokers" on ocean floors show us colonies of microbes can grow in the least hospitable places.

And not just hot, fiery places — life thrives in ice-cold ones, too. Microbes exist deep in Antarctic ice and can be buried for eons before being exposed to air and reviving themselves.

Does this fact, which is so well documented on Earth, point to potential for life among the icy moons of the outer solar system, or inside the icy cores of frozen worlds yet unknown, scattered around the Milky Way Galaxy?

We have approached the threshold of finding life elsewhere — with a suspicious rock from Mars — but only controversy resulted. Will humans find life when they go to Mars themselves? Or drill into Europa's icy crust?

Before humans travel to other planets, unmanned spacecraft may give us insight into the life question. ESA's Darwin and NASA's Terrestrial Planet Finder, currently being developed, will hunt for rocky planets around other stars, and we may be able to detect life from telltale spectral signatures seen from afar.

Even if life is plentiful, the odds of finding it in the cosmos may be remote. The distances are incredibly vast. But the search will go on, because the payoff could answer the most amazing question we can ask.

Yours truly,

David J. Eicher
Editor

Astronomy

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14	1.25"	82°	$199.00
18	1.25"	82°	$279.00
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28	2.00"	68°	$279.00
34	2.00"	68°	$299.00
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14	1.25"	60°	$89.00
20	1.25"	60°	$89.00
26	1.25"	60°	$99.00
32	2.00"	60°	$149.00
40	2.00"	60°	$199.00

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9) Variable Projection Camera Adapter (1.25")	$39.95
10) Anti-Vibration Pads – #895 (Set of Three)	

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Image by Jason Ware

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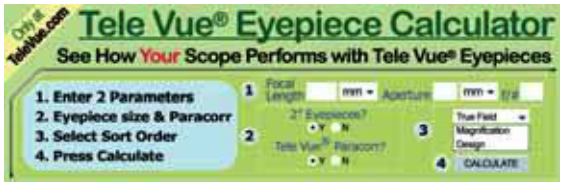

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Finding space rocks

"Killer impact" (December 2004) shows progress is being made in discovering almost the entire near-Earth object (NEO) population, and I believe author Bill Cooke draws attention to the work carried on by a few tenacious and dedicated people. There is, however, a rather

IMPACT BY A LARGE ASTEROID could have disastrous effects on Earth. Even worse, if such an object is discovered heading our way, no warning system or defense mechanism exists. *ASTRONOMY:* ROEN KELLY

disturbing consequence of this for the amateur astronomer.

Unlike the Oort Cloud, with its grand supply of comets, the asteroid belt has a limited number of substantial-size asteroids. As stated in the story, about 70 percent of NEOs have been discovered (down to about 1 kilometer in size).

Because it's sometimes difficult to tell an NEO from a main-belt asteroid if the apparent velocity is not high, these surveys find main-belt asteroids in large numbers.

Between 1998 and 1999, amateurs discovered a large number of asteroids from 17th to 19th magnitude. As amateurs, we were weaned on main-belt discoveries, and now, we turn our attention to providing NEO follow-up data for the large surveys.

It's sad to see the opportunity fade for amateurs to discover at least a small part of our solar system; to realize you are the first to know of that rock's existence; to know you are the first to see this asteroid since its start 4 or 5 billion years earlier.

Today, it's becoming rare for an amateur to find previously unknown asteroids even as faint as 20th magnitude. I fear the day is coming when discovering an asteroid is as rare as finding a new comet! This is an era of change and fleeting opportunity.

— GARY HUG, ESKRIDGE, KANSAS

I read Bill Cooke's article with interest and laud its concise information on what groups are doing to record the size of cosmic bodies, their numbers, and the possibilities of being hit by the larger bodies.

I was surprised Cooke did not mention ongoing work by others, such as Louis Friedman and Ann Druyan and the Planetary Society of Pasadena, California, which they head. They established Gene Shoemaker NEO grants [to aid amateurs in the NEO hunt].

The protection of our planet and its beings is of utmost importance and should not be treated lightly. Rogue cosmic bodies could, in an instant, end all that we have preserved, nurtured, and worked for — as well as our very existence.

This should be our wake-up call to put in a cosmic warning system so we have enough time to get ready. **— MIKE MARTINEZ,** LAKELAND, MINNESOTA

The future of space telescopes

I would like to comment on Robert Zimmerman's "The looming death of Hubble" (November 2004).

I've taught astronomy to fifth-graders for the past 5 years, and the images from Hubble fire my students' imaginations. When I teach them about the advantages and disadvantages of different kinds of telescopes available today, I always come to the advantages of having an optical telescope in space.

We knew Hubble wouldn't last forever, but the hope was something better would replace it. The next generation of astronomers is counting on the ability to see into space without our planet's atmosphere in the way. What will we tell them if there is no Hubble or similar scope in their future?

— MARIE CRIM, BUNKER HILL, WEST VIRGINIA

Postscript

Astronomy would like to acknowledge the Linda Hall Library of Science, Engineering, and Technology in Kansas City, Missouri, for its assistance with Wil Tirion's "The golden age of star maps" (December 2004).

— *ASTRONOMY* EDITORS

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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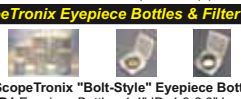

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BY BOB BERMAN

Major Ursa phobia

April in the mountains means all the suddenly awake bears start breaking into homes. Last summer, 20 local houses — including mine — were ransacked as the bruins searched for garbage. Now, they're back. Believe it or not, my whining about delinquent mammals relates to observing the night sky — at least, psychologically.

Animal-rights activists in ancient Greece immortalized bears with both a little and big version — both are at their highest in spring skies. You can trace the bear's shape in Ursa Major's stars if you have a few shots of vodka first. Otherwise, it looks like a dipper or a plow.

It's a mystery how disparate cultures like the American Indians, Germanic tribes, and ancient Greeks all saw a bear in these same stars. How could civilizations that never met visualize identical hallucinogenic shapes? They accomplished something truly historical: spreading misinformation *before* there was an Internet.

Each night this month, the Big Dipper appears higher at 10 o'clock until it reaches maximum altitude during April's final week. The pointer stars at the bowl's left then aim straight down to the North Star. This verticality is striking — one of the night's milestone moments. The topmost star, Merak, has a nice alien ring that sounds like a surname on Krypton. Below it, Dubhe (say Dubby, not Dubya) is a different story, because listeners chuckle, "C'mon, there's no star named Dubby."

What about the well-known concept of using the Big Dipper's whirling around the North Star as a clock, to tell time? Although a few books advocate this, it's idiotic. The Dipper goes around Polaris the wrong way, counterclockwise. So, it could serve as a 24-hour clock only if you could get *behind* those stars in another dimension, and look *this* way.

Like any broken clock, it gives the true time occasionally. Once a year, the "hour hand" (a line from Polaris to the pointer stars) correctly points straight up at midnight. When this happens depends on where you live in your time zone — it's generally between March 2 and 12.

Do you remember the first time you noticed the double star near the end of the Dipper's handle, composed of bright Mizar and little Alcor? "Al" means "the" in Arabic, so Al-stars fill the sky, as in Altair and Aldebaran. Alcor cryptically means "the abandoned one."

The ancient Arabs regarded spotting Alcor as a successful test of keen vision. These days, it's more like a feel-good exercise for nerds with terrible eyesight. Anyone can see it, even from light-polluted cities, so maybe the star has brightened throughout the centuries.

The sky's most famous bright double star also is the only one that never sets. You have to venture south of North Carolina to ever see it vanish. Safe bet: No one's ever gone to Dixie for that purpose.

Another oddity is that ancient Arabs called this double star the "horse and rider." But this is supposed to be a bear. Why drag the Kentucky Derby into the picture? Because the constellation wasn't a bear originally. The Sumerians and Babylonians called it a chariot. That definitely works better in this Rorschach spot than "Smokey the Bear." But before we give the Babs too much credit, remember: They originally called Orion a sheep.

Back to science. All Dipper stars except the two at the ends lie at the same 80-light-year distance from us. They share the same spectral type (A), nearly the same brightness, and the same motion through space. In other words: This is a star cluster. It's big because it's the nearest cluster to Earth.

Discovered in 1869, the Ursa Major moving group hovers so close that members and former members — perhaps even Sirius — lie all around us in the sky.

Because this entire region floats above the Milky Way's plane, only a smattering of stars lies between us and the emptiness of intergalactic space. That's why the famous Hubble Deep Field photo was taken in Ursa Major. No obscuring dust. Through this window, we can see countless galaxies beyond our own, including the bright pair M81 and M82 10 million light-years away. Both are found easily in binoculars by extending and doubling the diagonal line from Phecda (the highest bowl star) through Dubhe.

Not one 1st-magnitude star graces this whole lonely part of the sky. Yet, this most famous pattern in the heavens gave many of us our start long ago. These days, the "Ursa" component *still* gives me a start.

{ Why drag the Kentucky Derby into the picture? Because the constellation wasn't a bear originally. The Sumerians and Babylonians called it a chariot.

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MINUS VIOLET FILTERS The LUMICON Minus Violet Filter greatly improves photographs taken through lens systems, producing pinpoint star images. It is especially recommended for all telephoto lenses. The Minus Violet filter passes the maximum amount of visible light, including the full blue, green, yellow and red portions of the spectrum. It absorbs violet and ultraviolet light below 420nm, thus eliminating blue halos around bright stars in color photography. In B&W photography it eliminates bloated and swollen star images caused by violet and ultraviolet light, which telephoto lenses cannot focus perfectly, due to chromatic aberration. This filter is unsurpassed in photographic performance. 2" – $69.95 • 58mm – $79.95 • 72mm – $89.95

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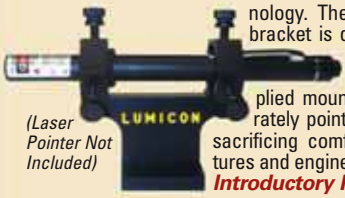

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BY GLENN CHAPLE

Gemini secrets

Are you one of those stay-at-homes

who watches the New Year's celebrations on TV? If so, you probably watch the traditional countdown at Times Square. During the last minute of the old year, a lighted ball gracefully descends the flagpole at One Times Square. When the ball reaches the bottom — Happy New Year! As a school teacher, I make use of a heavenly "Times Square ball" to count down the end of the school year. I'm referring to the "twin" stars Pollux and Castor in the constellation Gemini, and I watch their positions in the sky after sunset. In January, the two are visible above the eastern horizon. With each sunset, Pollux and Castor appear a bit closer to the setting Sun. Right now, this "New Year's ball" shines about halfway between the zenith and the western horizon after sunset. In late June, as the school year comes to an end, Pollux and Castor fade into the glare of the setting Sun — Happy Summer Vacation!

The Triplets

In 2005, Gemini could aptly be called the "Triplets," because Castor and Pollux are accompanied by a third bright "star" — Saturn. Of the telescopic objects that inhabit our night sky, few generate more excitement than Saturn. The fabled rings that always elicit a gasp of awe from first-time viewers can be glimpsed with an ordinary 2.4-inch (60mm) refractor and a magnifying power of just 25x. Under steady skies, a 3- or 4-inch scope and 100x will reveal the Cassini Division, a thin gap in the rings.

Saturn is attended by dozens of moons. The largest, Titan, is within a small telescope's grasp. A great beginner's project is to follow Titan's orbit around Saturn by making nightly observations during a 2-week span. Our Moon, near first quarter phase, lies near Saturn the evening of April 15. What a pair of telescopic treats!

STAR CLUSTER M35 (left) can be seen with binoculars. Look closely, and you can glimpse NGC 2158 (right). RUBEN KIER

Sextuplets

Castor is the "alpha" star of Gemini, even though its brightness doesn't warrant alpha-star ranking (Gemini's beta star, Pollux, is almost a half magnitude brighter). Castor is a striking double star — perhaps the finest in the Northern Hemisphere. Its 2nd- and 3rd-magnitude components, separated by a mere 4 arcseconds (″), are fair game for any backyard telescope and 100x magnification. This wasn't always the case.

In 1970, I couldn't resolve Castor with my 3-inch reflector. The reason? Castor is a binary star with an orbital period of some 450 years. In 1970, the two were a little under 2″ apart — too tight for my little scope. Since then, they have drifted farther apart and will continue to do so for the rest of this century. A 9th-magnitude star, located 73″ away, orbits the main pair. There's more!

Spectroscopic studies reveal each of the three stars in the Castor system is a close binary pair. Castor is a *sextuple* star! Whenever I gaze skyward at this seemingly singular point of light, I wonder at the stately cosmic dance of those six stars locked in gravity's embrace.

Clusters galore

No exploration of Gemini would be complete without a visit to the magnificent open star cluster M35 (NGC 2168). Its location, near the "foot" of Gemini, is shown in the all-sky map on page 51. An interesting sight in binoculars, M35 comes to life under telescopic scrutiny.

Small-aperture telescopes show dozens of cluster members in a splashy array that covers an area 30 arcminutes (′) across (the Moon's apparent diameter). Larger instruments will capture more than 100 stars. Use magnification around 50x.

If you look carefully near M35, you might catch a glimpse of the small, faint open cluster NGC 2158. I've seen it (barely) with a 3-inch scope, and only as a small, pulsing glow. A telescope with at least a 4-inch aperture is recommended (I just know I'm going to get an e-mail from someone living in Arizona who sees NGC 2158 regularly with the naked eye!). NGC 2158 is about 16,000 light-years away — 6 times more remote than M35.

April 16 is National Astronomy Day. Astronomy clubs and organizations across the country will celebrate the pursuit of this noble science. As of this writing, I haven't been invited to participate in any Astronomy Day activities. That's the astronomical equivalent of, well, not being invited out on New Year's Eve. Oh well.

Next month: We visit Chaple's School of Cosmic Dance. Clear skies.

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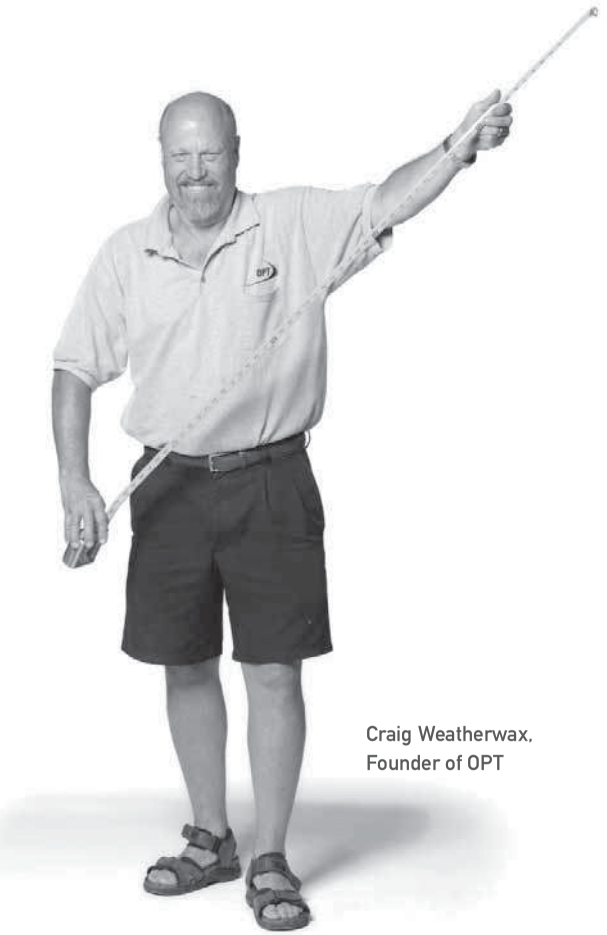

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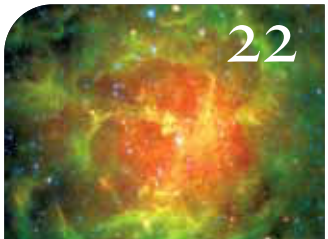
SWARMING WITH PULSARS. A team of astronomers has found 21 new, fast-rotating ("millisecond") pulsars in the massive globular cluster Terzan 5. They include 13 binary pulsars that will help astronomers test relativity.

news 04

Read all about it: Hubble photographs an extrasolar planet, NASA gets going on a robotic fix for Hubble, an odd rock on Mars, and the biggest stars in the known universe.

BUSY STAR FACTORY. Hot, blue stars mingle with dark threads of dust in NGC 346, the largest star-forming region in the Small Magellanic Cloud. NASA/ESA/STScI, A. NOTA



20 Dusty debris at Vega
22 Big Bang sound waves made galaxies cluster
24 Have martian volcanoes erupted recently?
26 Black holes crowd the galactic center

GALACTIC ASTRONOMY

Infant stars in the Small Magellanic Cloud

Astronomers using the Hubble Space Telescope (HST) have discovered a population of infant stars in the Small Magellanic Cloud (SMC). The stars, some 3,000 in number, have masses ranging from 2 times the Sun's down to half its mass.

"This result tells us for the first time that the SMC is making small stars down to a fraction the size of the Sun," says Antonella Nota (Space Telescope Science Institute), head of the discovery team that reported the finding at the American Astronomical Society's meeting in San Diego in January.

The team examined the large star-forming region NGC 346 using HST's Advanced Camera for Surveys, which has both sharp resolution and a wide field of view. The stars in the nebula seen by HST are all young in astronomical terms, about 5 million years old.

The SMC lies about 210,000 light-years away in the southern constellation Tucana. Visible to the naked eye, it is a satellite of the Milky Way.

Small and irregular, the SMC contains few heavy elements such as the Sun possesses and few places where stars are now forming. Because the SMC is relatively local, it gives astronomers close looks at a galaxy unlike the Milky Way in composition — and much more like the universe's first generation of galaxies. — **ROBERT BURNHAM**

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BROWN DWARFS

First exoplanet imaged?

The Hubble Space Telescope's NICMOS camera has likely made the first direct image of an extrasolar planet, say astronomers reporting to the American Astronomical Society in January.

The candidate object lies close to a young brown dwarf 225 light-years away in Hydra — but a small uncertainty remains that the object is orbiting the brown dwarf.

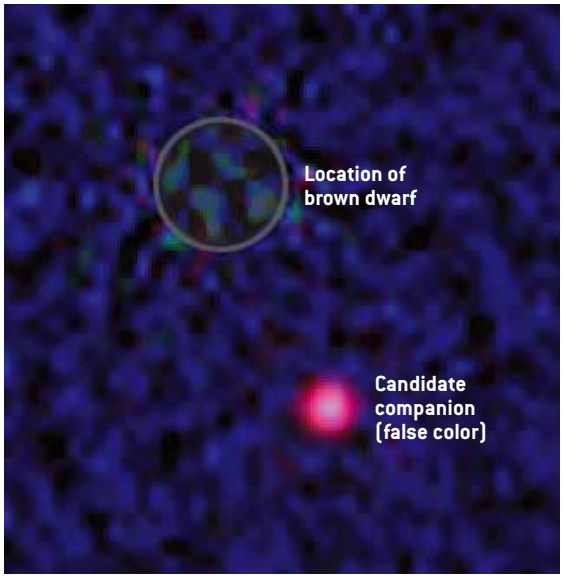
In April 2004, astronomers at the Very Large Telescope (VLT) in Chile detected a possible planet around the brown dwarf, 2MASSWJ 1207334–393254. But they couldn't confirm it.

The candidate planet shines with only a hundredth the brightness of the brown dwarf, and it has a temperature of some 1,800° F (1,250 kelvins) — cooler than a lightbulb filament.

Glenn Schneider (University of Arizona) led the team using Hubble to study the object. Says Schneider, "The NICMOS positions, relative to the VLT's, indicate it's a true companion." He rates the chance of the object not being a planet at only 1 percent.

If this proves to be a planet, says Schneider, "it has about 5 times the mass of Jupiter." And it would orbit at a distance of 54 astronomical units, he says. One "year" for the planet would last 2,500 Earth years.

Schneider plans to follow up with NICMOS in April 2005. — R. B.



WARM COMPANIONSHIP. Astronomers have probably imaged an exoplanet for the first time. It orbits a brown dwarf and glows a bit cooler than a lightbulb filament. NASA/ESA/UNIV. ARIZONA, G. SCHNEIDER

WATCH THE DUST. Rocky objects orbiting the star Vega must have collided recently. ARTWORK: NASA/JPL/CALTECH, T. PYLE

STELLAR ASTRONOMY

Vega's dustup

The dusty disk around the bright star Vega is the relatively recent product of a collision involving Pluto-size bodies orbiting the star, say astronomers.

Kate Y. L. Su (University of Arizona) headed a team using the Spitzer Space Telescope to study particles in Vega's disk. They found the dust grains are so small that starlight would push them out of the system in about 1,000 years. The total amount of dust in the disk is about a third of our Moon's mass.

"We are witnessing the aftermath of an event that probably happened within the last million years," says Su. — R. B.

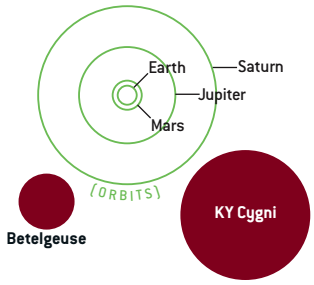
STELLAR ASTRONOMY

The biggest stars

A team of astronomers led by Philip Massey (Lowell Observatory) has found three red supergiant stars bigger than any known before. The previous record-holder, Mu Cephei, now ranks fourth in size.

The three largest are KW Sagittarii, V354 Cephei, and KY Cygni, all with diameters 1,500 times the Sun's.

Using telescopes in Arizona and Chile, the team got the most accurate temperatures yet for the coolest red supergiants: about 3,450 kelvins, or 5,720° F.



BIG BROTHER. Red supergiant KY Cygni is more than twice the size of Betelgeuse. LOWELL OBS./P. MASSEY

"These stars aren't the most massive known," says team member Emily Levesque (MIT). "But modestly high luminosities and relatively low temperatures make them the biggest stars known," she says. — R. B.

HUBBLE SPACE TELESCOPE

Will Dextre fly to HST's rescue?

While astronomers argue the Hubble Space Telescope (HST) requires a manned servicing mission, NASA has chosen MacDonald, Dettwiler, and Associates Ltd. (MDA) of Brampton, Ontario, to develop a design concept for a robotic servicing mission.

THE ROBOT OPTION. NASA has chosen a firm to develop a robotic repair and upgrade mission for Hubble. ARTWORK: MDA

The technology is based on Dextre, the two-armed robot MDA built for maintenance of the International Space Station. The mission would also attach a de-orbit module to bring HST down safely at the end of its life.

In December 2004, a report issued by the National Academies' National Research Council concluded a robotic mission was too limited to be feasible, and strongly recommended a manned mission to refurbish Hubble.

Should NASA continue with a robotic mission, launch is not likely before December 2007. Hubble's batteries or gyroscopes could fail by then, leaving no way to fix the telescope after that point. — LIZ KRUESI

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BLACK-HOLE RACETRACK. For the first time, astronomers have observed three hot blobs of gas making complete orbits of a black hole at the center of galaxy Markarian 766.

BABIES ONBOARD. Newborn stars are emerging from dense cores of dust deep within the Trifid Nebula, seen here in infrared light with the Spitzer Space Telescope. NASA/JPL/CALTECH/J. RHO

STELLAR ASTRONOMY

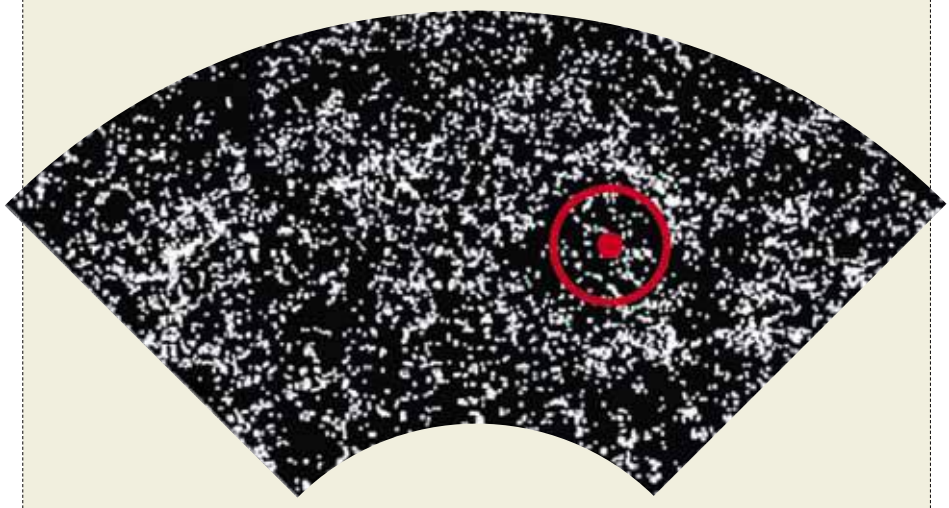
Star incubators dot the Trifid Nebula

Astronomers using the Spitzer Space Telescope have discovered warm, dusty incubators where newborn stars are rapidly growing, deep in the Trifid Nebula (M20).

"We were surprised to see stellar embryos in the densest cores," says Jeonghee Rho (Spitzer Science Center), principal investigator for the observations. Astronomers had long thought the densest cores were all but starless, she says. The nebula is only about 300,000 years old.

The southern part of the Trifid Nebula is energized by a single, hot, type-O star, says Rho. She and Spitzer Center coworker William Reach found 30 embryonic stars located along dark clouds and dust lanes, and they spotted 120 newborn stars lying along the fronts of ionized regions.

"The protostars grow by a solar mass every thousand years," notes Reach. "Those growing fastest become the biggest." — **R. B.**



FROZEN SOUND. Galaxies mapped by SDSS reveal a pattern reflecting ancient sound waves in the cosmic background. The red dot-and-circle shows the sound waves' characteristic size today. SDSS

Big Bang sound waves influenced the clustering of galaxies

Sound waves from the Big Bang imprinted a pattern on the expanding universe that explains the clustering of galaxies, two independent research teams confirm. The finding was announced in January at a meeting of the American Astronomical Society.

The Sloan Digital Sky Survey (SDSS) and the 2 Degree Field Galaxy Redshift Survey (2dFGRS) used different wavelengths, instruments, and methods to map tens of thousands of galaxies across substantial volumes of space. The teams agree, however, their respective surveys determined galaxy clusters are about 1 percent more likely to clump on distance scales of about 500 million light-years. While the enhancement is weak, both surveys detected it.

"The triumph is that the signal is seen at the expected location," says Richard Ellis (Caltech), a 2dFGRS team member. The result confirms previous studies that found a large-scale structure frozen into the cosmic microwave background radiation, the remnant glow of the Big Bang.

In 2003, researchers using data from NASA's WMAP satellite discovered the microwave background has ripples that theorists identified as sound waves emitted shortly after the Big Bang.

The sound waves began to impose their effect about 400,000 years after the Bang. That was when matter and light started to separate. The fleeing photons made matter reverberate, producing pressure waves, or in essence, sound.

The separation process ended about a million years post-Big Bang. The waves were then about 500,000 light-years across, according to Daniel Eisenstein (University of Arizona), an SDSS team member. As the universe expanded, he says, this distance grew to its present 500-million-light-year size. The slight density increase at the wave's leading edge influenced the formation and spacing of galaxy clusters.

The new finding also supports the idea the universe contains about 4-percent ordinary matter, 25-percent dark matter (whose nature is largely unknown), and roughly 70-percent dark energy (whose nature may be the biggest unsolved problem in physics).

"The concordant picture we have of the universe is hanging together amazingly well," says cosmologist Martin Rees (Cambridge University). — **R. B.**

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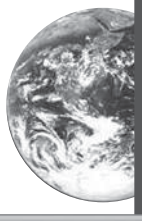

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FAILED SPACECRAFT SEES STARS. NASA's Wide-Field Infrared Explorer satellite failed in 1999, but its star camera still works. It has now imaged previously unseen companion stars in two binaries, Lambda Scorpii and Mu Eridani.

Pedestal crater

ROCKY BLANKET. The impact that made this crater in Noachis Terra on Mars threw out a bouldery sheet of ejecta. The rocks protected the underlying ground from erosion, leaving the crater on a pedestal. This Mars Global Surveyor image, sunlit from the upper left, is about 1.9 miles (3 km) across. NASA/JPL/MSSS/IMAGE R23–00448

ODD ROCK. Pitted and shiny, the rock dubbed "Heat Shield" is a meteorite. NASA/JPL/CORNELL

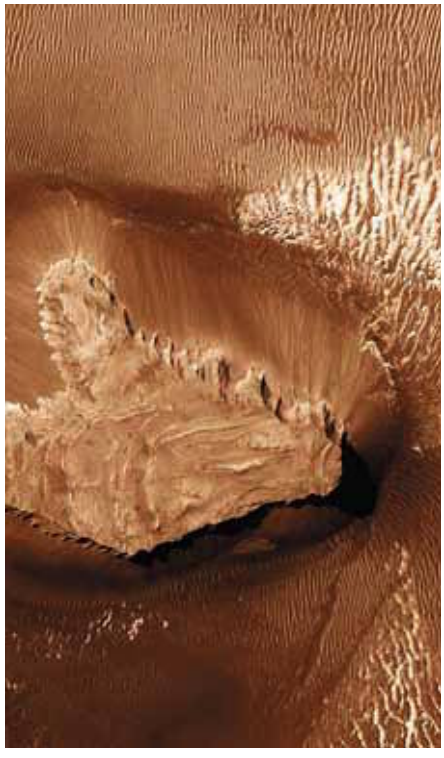
PLANETARY SCIENCE

Rover finds iron meteorite on Mars

Exploring where its heat shield landed, Mars rover Opportunity discovered a nickel-iron meteorite about the size of a basketball. It is the first meteorite found on another planet.

Scientists confirmed the "rock" was metal with the rover's Mössbauer spectrometer. They chose not to grind the meteorite after Earth tests showed it would damage the grinding tool.

"I've been telling the rover drivers not to hang around here," quips project scientist Steve Squyres (Cornell University). "This is a part of Mars where metal falls from the sky." — R. B.



SEDIMENTARY MESA. Light-toned sedimentary deposits scribe curving lines atop this mesa in northern West Candor Chasma on Mars. Dark, wind-blown dunes surround the mesa. Sunlit from the upper left, this Mars Global Surveyor image is about 1.9 miles (3 km) across. NASA/JPL/MSSS/IMAGE R21–00326

PLANETARY SCIENCE

Mars volcanoes may be active

Lava erupted on the flanks of the large martian volcano Olympus Mons perhaps only 2.4 million years ago, says a team of planetary scientists who studied detailed images from the Mars Express spacecraft.

CRATER-FREE. The western flank of Olympus Mons has rocky debris flows so uncratered, they may be only 4 million years old. ESA/FU BERLIN

"These volcanoes are potentially still active today," says Gerhard Neukum (Freie Universität Berlin), leader of the team, which reported in *Nature* (December 23–30, 2004).

Moreover, Neukum says, glacial deposits as young as 4 million years ring the base of Olympus Mons. Running down from the scarp that circles Olympus Mons are tongues of rocky debris with no craters on them.

"These are so young," the team says, "that they cannot be reliably dated."

But the young crater ages raise questions. Mark Robinson (Northwestern University) says a big pitfall is the martian cratering rate, a number he describes as poorly known. "Caution's the word," he says. — **R. B.**

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Richard Wolfson (Ph.D., Dartmouth College) is Professor of Physics at Middlebury College in Vermont. Decades of teaching at Middlebury, with its strong emphasis on the humanities, have made him an expert at demonstrating the logic and significance of physics to students from many fields. His writings have appeared in *Scientific American*. He is author of *Physics for Scientists and Engineers*.

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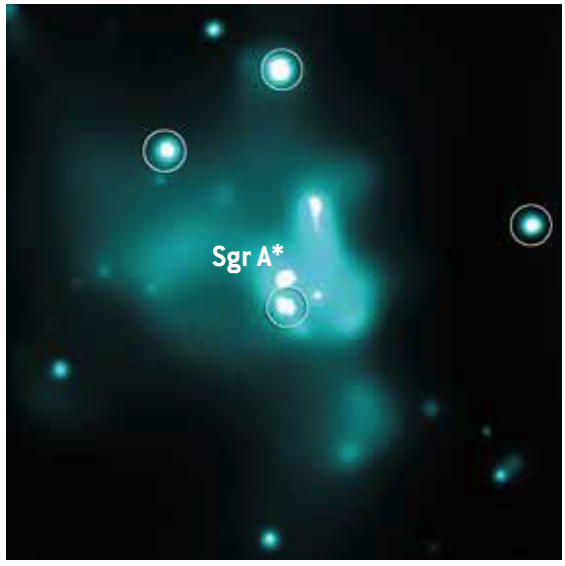
KING OF SPIN. Astronomers found a star, FK Comae Berenices, rotating nearly 200 times faster than the Sun. They believe the high speed resulted when two Sun-like stars forming a binary pair merged to make one star.

Barred spiral prototype NGC 1300

BEAUTY BAR. The galaxy NGC 1300, seen in this exquisitely detailed image by the ACS instrument on the Hubble Space Telescope, shows old, red stars and dust lanes in its bar, plus hot, blue stars and red hydrogen gas clouds in the arms. NASA/ESA



TOKEN NUMBERS. Four X-ray emitting black holes (circled) lie within a few light-years of the Milky Way's center, designated Sgr A*. The number found implies a much larger population of black holes — perhaps thousands. NASA/CXC/UCLA

GALACTIC ASTRONOMY

Black holes swarm the galactic center

As many as 10,000 black holes lie close to the Milky Way Galaxy's core, say astronomers who studied the galactic center with the Chandra X-ray Observatory. They reported at the American Astronomical Society's January meeting.

The black holes have masses of a few suns and are separate from the supermassive black hole at the Milky Way's center, Sagittarius A* (Sgr A*).

Michael Muno (UCLA) and his coworkers monitored the region within 70 light-years of Sgr A*, looking for X-ray sources. They found hundreds but concentrated on the brightest and most variable. This cut the number to seven, of which four lay within 3 light-years of Sgr A*.

"We thought we had only a 1 in 5 chance of finding a single black hole within 3 light-years of Sgr A*," says Muno. Finding four X-ray-active black holes in a small region suggests a larger total population.

The finding supports a prediction by Mark Morris (also UCLA) that black holes would drift toward the galactic core as they interact with low-mass stars. Some stars are thrown away from the core, while others are devoured by the black holes. — **R. B.**

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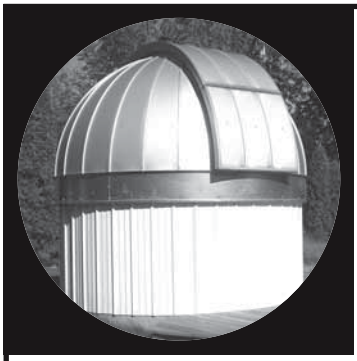

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Astronomy magazine

HA0705

Quest for a living

How do you search for extraterrestrial life when you don't know what it will look like? /// BY ALAN LONGSTAFF

Will we recognize alien life if we stumble across it?

Maybe not. It's highly unlikely, after all, that the cameras of our space probes will capture images of planetary surfaces covered with organisms, or the artifacts of intelligent life-forms.

Chances are the evidence will be much more subtle: tantalizing spectral lines of biomolecules in the light from a distant earthlike world, or structures within rocks from another planet that are not of obvious geological (or even biological) origin. When we discover any such evidence — actually, long before we reach that point — we're going to need a working definition of what life is and how we'll recognize it.

Astrobiologists argue some properties must be universal to life wherever it occurs. First, life is a complex chemical system able to replicate itself and undergo evolution. Those organisms best-suited to their surroundings survive in larger numbers to reproduce, and this process drives the change and diversity so characteristic of life on Earth.

Second, all known life is carbon-based. No other chemical element gets remotely close to carbon for the variety of its chemical interactions, a flexibility that is crucial for living systems.

Third, life almost certainly will need liquid water. Biochemistry is about molecules colliding with each other in the right way and at the right speed, and this requires a liquid solvent. Water happens to be about the best solvent around, although not the only one. It remains liquid over a wide temperature range and, best of all, there's lots of it everywhere — even, for example, in the star-forming regions of the Orion Nebula.

How common life is in the universe depends on the number of stars with planetary systems, the fraction with habitable planets, and how easily life gets started. Astrobiologists are refining their estimates of these factors.

Over 120 extrasolar planets have been found orbiting 105 stars. Most are gas-giant planets orbiting close to their parent star ("hot Jupiters") or in highly eccentric orbits. The hot Jupiters are thought to form a long way from their star and migrate in. Planetary scientists run computer simulations that show hot Jupiters form and migrate early in the development of planetary systems. If a growing planetary system retains enough dust for the much slower building of terrestrial planets, then about half the known extrasolar systems could form Earth-mass planets in their habitable zones (see "Habitable zones," page 33).

FINDING ALIEN LIFE easily would count as the greatest scientific discovery ever. Scientists have only one example — Earth — to go from, but even here, life is tenacious, occupies every available niche, and can survive under astonishing conditions. *ASTRONOMY:* ROEN KELLY

universe

Gas giants in highly eccentric orbits usually eject terrestrial planets from the system. Even so, computer studies show a third of known extrasolar systems able to make Earth-mass planets in habitable zones keep them. Encouragingly, some simulations produce planetary systems that resemble our solar system — but only when the gas giants remain in stable orbits far beyond the habitable zone.

Currently, the only measure of how easy it is to make life is to consider the time from Earth's formation, 4.56 billion years ago, to when life originated. The first organisms on Earth left no fossils, so we have to tease out subtle traces of their biochemistry imprinted in the few rocks that remain from those remote times. The earliest circumstantial evidence for life (gleaned by Stephen Mojzsis of the University of Colorado) is an enrichment of a light isotope of carbon (^{12}C) in metamorphosed sedimentary rocks from West Greenland that are 3.85 billion years old. If we take this at face value, then life got started on Earth rapidly. And if life originated on Earth as soon as conditions allowed, it suggests life is common in the universe.

Inferno

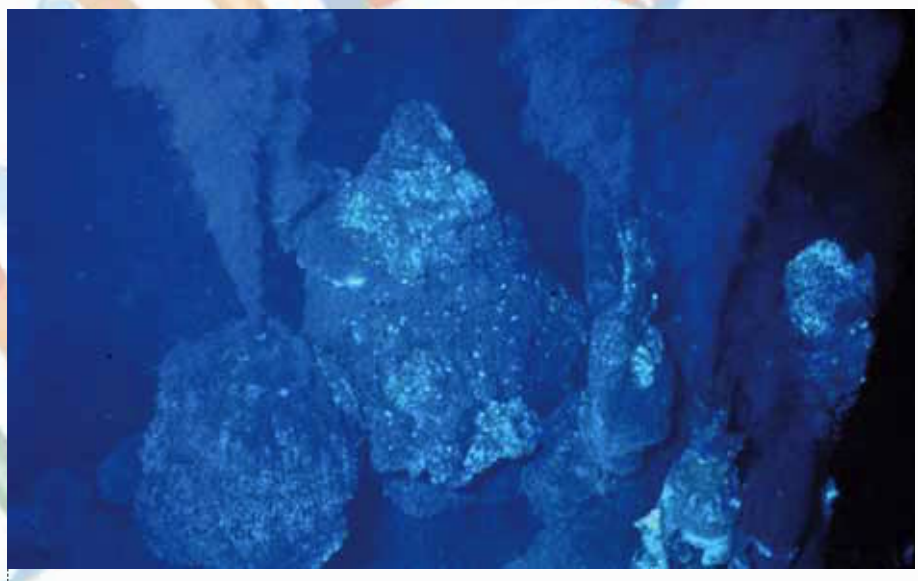
Early Earth was a hellish place. Around 3.85 billion years ago, the massive meteorite impacts that marked the end of planet building had barely ceased. Oceans at a temperature close to boiling covered most of the surface, and the atmosphere, outgassed in just a million years by awesome levels of volcanism, was largely nitrogen, carbon dioxide, and water. There was no oxygen and, hence, no ozone to provide protection from solar ultraviolet radiation. The ionizing power of this radiation would render any land surface and the top few feet of water uninhabitable.

At first sight, early Earth seems totally inhospitable. But over the past few years, scientists have found microorganisms that live among — indeed require — conditions once thought hostile to life. Among these are hyperthermophiles, organisms that thrive in high-pressure water up to 242° Fahrenheit (117° Celsius) without sunlight or oxygen. These astonishing microbes live in and around hydrothermal vents on the ocean floor where new oceanic crust is forming. There, Earth's hot mantle lies close to the surface. Seawater percolates into the crust, is heated to 660° F (350° C) by hot mantle rock, and erupts as a "black smoker" laden with dissolved gases, such as hydrogen, plus metals.

All oxygen-breathing organisms get the energy they need by "burning" hydrogen derived from organic molecules (foodstuffs such as sugars) in oxygen. Plants and many bacteria go one step back and harness sunlight to make the organic molecules from carbon dioxide through photosynthesis. Hyperthermophiles don't need organic molecules or sunlight. They get energy by odd metabolisms that, for example, burn hydrogen with sulfur or carbon dioxide, with all the ingredients supplied by the black smoker.

All terrestrial organisms contain within their cells molecules of ribonucleic acid (RNA), which has a chemical sequence unique to each species. The more closely related two species are, the more alike their RNA sequences.

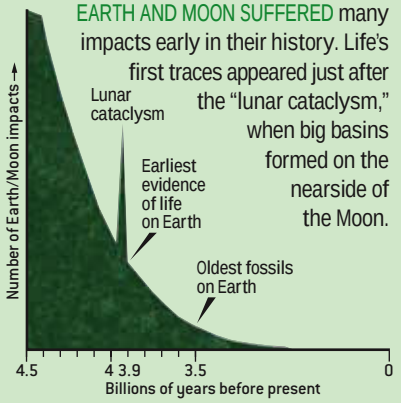
By comparing the RNA sequences of a representative number of organisms, scientists can work out a family tree for life on Earth. Astonishingly, this reveals the root and lowest branches of the tree are occupied by hyperthermophiles. Thus, life almost certainly started at high temperature. However, we cannot rule out the possibility that life started at low temperature (perhaps elsewhere in the solar system) and



BLACK SMOKERS support entire ecosystems. At the base of the food chain are remarkable heat-loving organisms that glean energy and carbon for life from inorganic materials dissolved in superheated water erupting from the ocean floor. This is life without sunlight or oxygen, and early life may have resembled it. ROBERT EMBLEY, NOAA PACIFIC MARINE ENVIRONMENTAL LABORATORY/MICHAEL PERFIT, UNIV. OF FLORIDA/NOAA VENTS PROGRAM

/// Lunar cataclysm

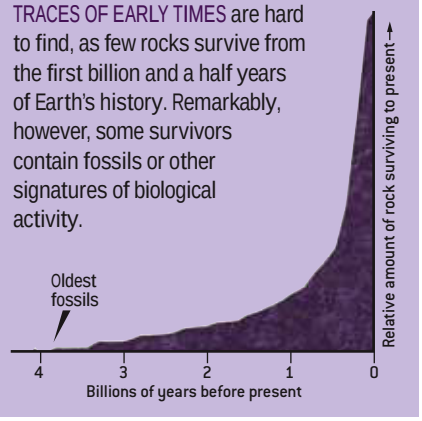
EARTH AND MOON SUFFERED many impacts early in their history. Life's first traces appeared just after the "lunar cataclysm," when big basins formed on the nearside of the Moon.



ASTRONOMY: ROEN KELLY, AFTER B. A. COHEN

/// Ancient rocks are rare

TRACES OF EARLY TIMES are hard to find, as few rocks survive from the first billion and a half years of Earth's history. Remarkably, however, some survivors contain fossils or other signatures of biological activity.



ASTRONOMY: ROEN KELLY, AFTER E. L. SHOCK, J. P. AMEND, AND M. YU. ZOLOTOV

Alan Longstaff *started out as a biochemist and now teaches astronomy at the Royal Observatory Greenwich in London.*

APTLY NAMED, *Bacillus infernus* is a hyperthermophile living deep in Earth's crust. This organism breathes iron and manganese dioxide; oxygen poisons it. HENRY ALDRICH, UNIV. OF FLORIDA

that hyperthermophiles subsequently evolved. The tree of life shows these were the only traces of early life to survive, with the rest obliterated by the high temperature on early Earth.

Since the early 1990s, many species of viable bacteria, including hyperthermophiles, have been found several miles deep in the warmth of Earth's crust, as predicted years earlier by Thomas Gold of Cornell University. The deep crust may have been the only refuge for early life, affording it protection from the effects of giant impacts that would have boiled away oceans and filled the atmosphere with incandescent rock vapor.

But as the rate of impacts lessened, the temperature of Earth's surface cooled, and oceans began to endure. Thermophile life spread from its deep refuges and evolved into organisms that could survive in the cooler realms nearer the surface, even altering the oceans and atmosphere chemically by liberating oxygen and other byproducts. Although we can no longer live together in the same places, we are the descendants of those thermophiles.

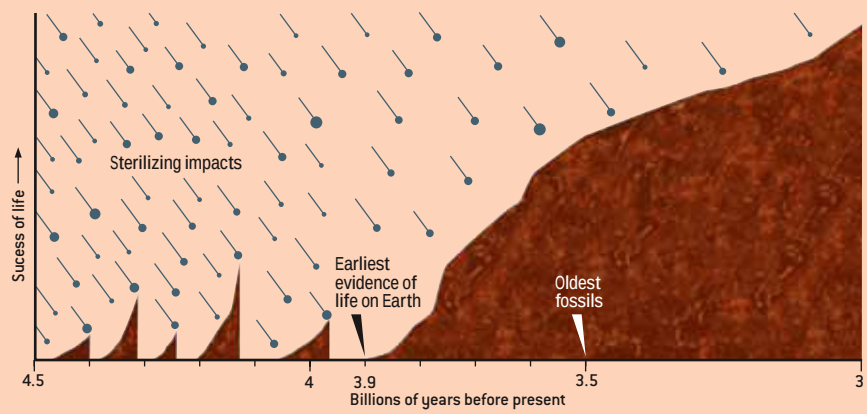
On ice

When life emerged from its deep, hot bottleneck, it developed into a larger and more varied biosphere. Terrestrial life's origin and diversification give scientists hope for finding other places where life also could have started. Besides Earth, two locations in the solar system stand out as prime candidates: Europa and Mars. These are two worlds that have — or once had — liquid water as a biological solvent. If we follow the water, we may be able to find life.

Jupiter's moon Europa teaches us to think laterally. It lies far outside the habitable zone, not receiving enough sunlight to keep water liquid on its surface or to drive photosynthesis. But beneath its icy crust may lie a salty water ocean perhaps 60 miles (100 kilometers) deep. Evidence for this is that a third of Europa's surface resembles pack ice in the Arctic and Antarctic, suggesting it has partially melted and refrozen. Calculations reveal the moon's ice crust can be no more than about 5 miles (8 km) thick. Tidal tugs from Jupiter and Europa's two flanking moons, Io and Ganymede, heat the ocean and keep it liquid.

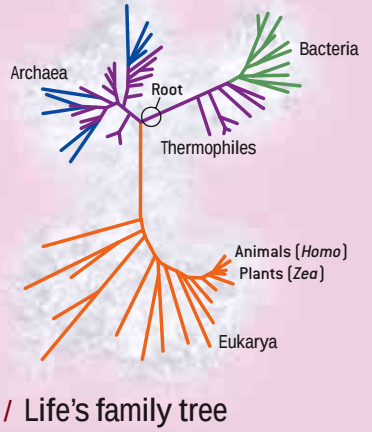
/// The Miller-Urey experiment

AN ELECTRICAL SPARK, plus water, plus gases thought to match Earth's first atmosphere (methane, ammonia, and hydrogen) created prebiotic amino acids in an experiment by Stanley Miller and Harold Urey in 1953. However, scientists now think the early atmosphere held primarily carbon dioxide and nitrogen, and the energy for creating life came more from chemical and geothermal sources. *ASTRONOMY:* ROEN KELLY



/// How many times did life begin afresh?

DID LIFE HAVE MORE THAN ONE GENESIS? Impacts big enough to sterilize Earth occurred often during the planet's earliest days. If life began in that violent era, it probably started several times and was wiped out again and again. Scientists speculate the final planet-sterilizing impact happened around 3.9 billion years ago, and all of today's life is descended from a common ancestor that appeared after that event. *ASTRONOMY:* ROEN KELLY, AFTER J. W. SCHOPF



/// Life's family tree

THE TREE OF LIFE has three major branches, and each evolved from organisms that liked it hot. All life today is descended from thermophile organisms that could survive intense heat. *ASTRONOMY:* ROEN KELLY, AFTER E. L. SHOCK, J. P. AMEND, AND M. YU. ZOLOTOV

/// MARS: WARM AND WET?

SEVERAL FINDINGS are hard to reconcile with the idea of a warm and wet early Mars. Water dissolves carbon dioxide in the atmosphere and normally would combine with surface materials to form carbonate rock, such as limestone. Although trace amounts of carbonates have been identified at the surface, Mars shows nothing like the expected amount.

However, discoveries on Meridiani Planum by the Mars rover Opportunity show that the surface water there would have been acidic. In this situation, carbonates would not be deposited.

The mineral olivine, present in basalt rocks, is converted by water to serpentine in just tens of years. Yet surveys by spacecraft find huge areas of exposed, unweathered olivine on Mars. Moreover, planetary scientists find no trace of clays, the final product of water acting on igneous rocks. All this suggests liquid water did not linger at the martian surface.

The mineralogy of Meridiani Planum supports this interpretation. For example,

FLOWING WATER eroded Mangala Valles and many other outflow channels on Mars. But planetary scientists are unsure how long the floods persisted and when they occurred. NASA/JPL

the hydrated mineral jarosite, found by Opportunity, forms when basalt is exposed to acid water under a variety of conditions — but jarosite does not survive prolonged immersion in water.

A simulation of giant impacts, by Teresa Segura and colleagues at the University of Colorado and NASA's Ames Research Center, depicts early Mars as endless winter, briefly punctuated by searing temperatures and scalding rains after large impacts. The impacts heat the atmosphere to more than 900° F (500° C), vaporizing subsurface permafrost. Torrential rainfall and flash floods carve valleys and erode craters. But within a century or so, everything refreezes.

If correct, this scenario offers bleak prospects for life on Mars unless it was protected deep in the crust.

CHAOTIC TERRAIN ON EUROPA resembles pack ice on Earth, providing evidence for an ocean under the moon's ice crust. Measuring shadows cast by the raised ice rafts allows scientists to calculate the thickness of Europa's crust and the dynamic forces changing it. The latter include plumes of warmer ice that cause local melting and resurfacing. NASA/JPL

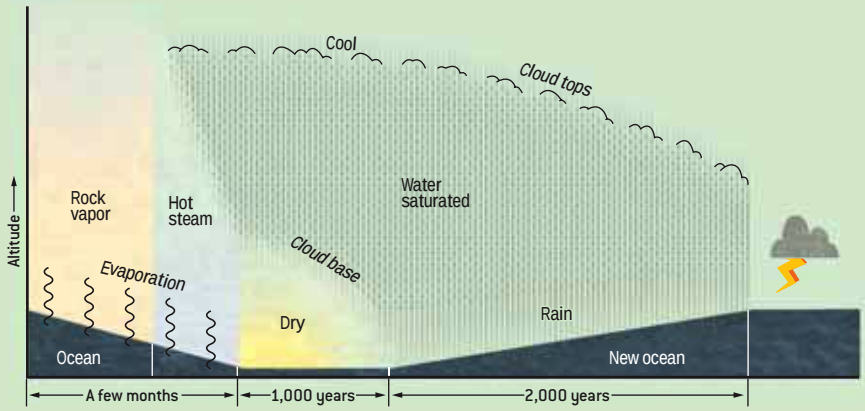
Although entirely speculative, Europa could have submarine hydrothermal systems like those on Earth where life may have arisen. There is even a mechanism, proposed by Chris Chyba of The SETI Institute and colleagues at Stanford University, to deliver oxygen to the ocean.

Water ice at the surface of Europa is continually bombarded with charged particles from the Sun and Jupiter, which make oxygen as they break up the ice's water molecules. Impacts churn the oxygen to a depth of about a yard. If the top of Europa's ice crust mixes with the ocean over geological timescales, sufficient oxygen could reach the ocean to support microbial life with modest oxygen demands.

Red planet

In all the varied worlds of the solar system, everyone's favorite candidate for exo-life is Mars. The case for past life on Mars is based on the hypothesis that the planet was once warm and wet. Early Mars must have been volcanically active and would have outgassed an atmosphere rich in carbon dioxide and water.

This would be crucial because a substantial greenhouse effect would have been needed to prevent Mars from freezing over, given its distance from the Sun. Unfortunately, Mars lost its global magnetic field about 3.9 billion years ago, when its cooling core stopped generating a field. This let cosmic radiation strip away



/// What happened when impacts evaporated oceans

HELL ON EARTH followed extremely large impacts, which were common in the planet's early history. Each big impact dumped enough heat into the crust to boil away the oceans while filling the atmosphere with vaporized rock. Eventually, the atmosphere cooled sufficiently to let rain reach the surface, and oceans began to collect. The next big impact started the cycle afresh.

ASTRONOMY: ROEN KELLY, AFTER K. J. ZAHNLE AND N. H. SLEEP

much of the martian atmosphere, and the temperature plummeted to today's average surface temperature of –60° F (–50° C). Despite this, there is good evidence from NASA's Mars rovers, the European Space Agency's (ESA) Mars Express orbiter, and earlier missions, that liquid water once flowed on Mars. Recent data suggest lots of water remains locked up as permafrost in the ground.

If life did start on Mars, one thing is clear: It would not have been at the surface. Mars is bombarded by cosmic and ultraviolet radiation, and its surface rocks are highly oxidizing, making them chemically toxic to life-forms like ours.

What would an underground martian biosphere be like? Microorganisms adapted to the cold seem a reasonable bet, perhaps at the depth where the permafrost melts. This would match the lowest temperature — 0° F (–18° C) — at which terrestrial microbes can grow and reproduce. Perhaps paradoxically, if martian life were deeper in the planet, maybe what survived were thermophiles like those in Earth's crust. Whichever scenario is the case, we will need deep-drilling rigs to find evidence. This appears unlikely in foreseeable robotic missions.

The discovery of methane in the martian atmosphere is highly intriguing. Unless some process is continuously making it, methane won't hang around for more than a few hundred years. Possible sources are volcanic or geothermal activity, a recent comet impact, or life. (Most methane in Earth's atmosphere comes from microorganisms.)

On Mars, the methane tends to concentrate where subsurface water is abundant. This remarkable correlation, while suggestive, needs to be tempered by estimates of the rate of martian methane production. These show that if the gas is biogenic, the martian biomass can be only around 20 tons. Very small fry indeed.

Are we martians?

If past or extant life is discovered on Mars, two possible outcomes follow, both profoundly interesting.

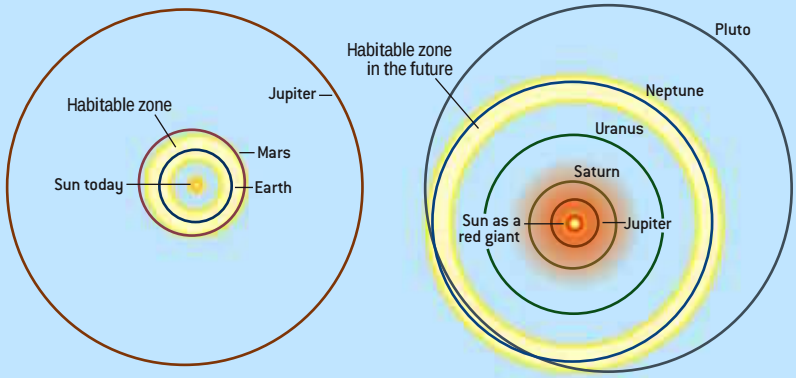
The first outcome is that Mars life turns out to have a biochemistry obviously like that of Earth. If this proves the case, we can conclude either terrestrial life was derived from Mars or (less likely) terrestrial life infected Mars.

/// HABITABLE ZONES

ASTRONOMERS DEFINE a habitable zone as the region of space around a star where a planet can have liquid water on its surface. The zone's location depends on the star — the hotter the star, the farther out the zone will lie (and the wider it will be).

Habitability also depends on a planet's atmosphere. If it contains a large amount of a heat-trapping greenhouse gas such as carbon dioxide, a planet can remain habitable farther from the star. For life to start and survive, the zone must remain continuously habitable over geological timescales. For this reason, astronomers regard only low-mass, main-sequence stars as candidates for habitable planets. Sunlike stars have main sequence lifetimes around 10 billion years, and red dwarfs are even longer-lived. More massive stars live too short a time for life to develop very far even if it gets started. And a star of just 3 solar masses lives for only 500 million years on the main sequence.

But a complication emerges due to stellar aging. As a star evolves, its luminosity generally increases. This drives the habitable zone outward. In extreme cases, the entire zone moves away from its earlier range, condemning any life unlucky enough to emerge on a planet within the formerly habitable zone. In other star systems, including our own, a continuously habitable zone may exist during most of the star's life, even while its inner and outer edges change with the star's brightness. In the Sun's case, for example, the zone that has always been habitable runs from 0.95 astronomical unit (AU) to 1.15 AU.



NOTHING IS FOREVER. As the Sun ages and becomes a red giant, its habitable zone will move outward — far outward. Earth and the other inner planets will be absorbed and vaporized or simply charred to a cinder, along with any life still living there. Before this scenario unfolds millions of years from now, life will need to find a new home. *ASTRONOMY:* ROEN KELLY

Paul Davies of Maquarie University in Australia has proposed Mars was a better place for life's origin than Earth. Because it has only one-tenth Earth's mass, he argues, Mars would have suffered less bombardment early in its history and would have cooled quicker. This would allow conditions for life to be met earlier on Mars than on Earth. Thirty-two meteorites are known to have come from Mars, so some exchange of rocks between the two planets has occurred.

Calculations by planetary scientists give good reason to believe some microorganisms could survive the impacts at launch and arrival, plus a lengthy journey through interplanetary space, provided they were surrounded by about a yard of rock to shield them from cosmic radiation. Rocks at the edge of an impact can attain escape velocity without undue heating or shock. Terrestrial bacteria have survived acceleration forces of 33,000 Gs and the vacuum and cold of space for over 2 years, and their spores can spend perhaps millions of years in suspended animation.

The second outcome is that the biochemistry on Mars differs from that on Earth, implying that martian life had a separate genesis. This would be of profound interest in itself and also for its larger implication. That life got going on two planets in the same stellar system would strongly suggest it is abundant in the universe.

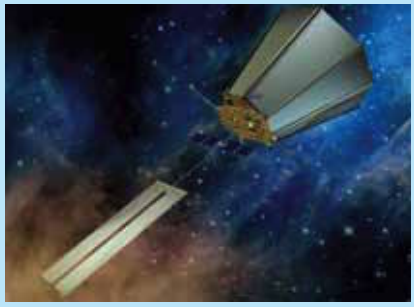
Beyond the solar system

How will we know which exoplanets may harbor life? The answer is to look for telltale signs in their light.

TWO MISSIONS WILL LAUNCH in the next decade to begin the hunt for habitable planets. Darwin (below), an ESA mission, will have six 1.5-meter (4.9-foot) telescopes flying in formation, their mutual distances controlled to high precision by laser signals.

Light from a target star will be blocked by a clever trick called nulling interferometry. The technique works by delaying the light slightly in three of the telescopes, forcing it 180° out of phase with respect to the other instruments. This produces destructive interference; the wave crests in one telescope cancel the wave troughs in a second. Light coming from near the star, however, such as from an exoplanet, is less affected and is not suppressed.

The other mission, the Terrestrial Planet Finder (TPF), combines two NASA projects. One project closely resembles Darwin, while the other will observe at optical wavelengths (see below). This half of TPF seeks planets using a coronagraph, an instrument that places an opaque disk in the telescope's optical path to block the star's direct light.



NASA'S TERRESTRIAL PLANET FINDER (above) comprises two missions to search for possibly inhabited extrasolar planets. TPF-I will search in the infrared part of the spectrum using an interferometer to detect planets. Meanwhile, TPF-C (shown above) will hunt for planets using an optical telescope with a blocking disk to reduce glare from each star being studied. NASA

ESA'S DARWIN MISSION (left) will survey the nearest several thousand sunlike stars to search for the chemical signature of life in the light from extrasolar planets. ESA

Living organisms mess up the chemistry of their environment. This chemical disequilibrium can show itself as the presence of a molecule that can be explained only if some process is continually regenerating it. For example, our atmosphere contains oxygen only because photosynthesis makes it faster than it is lost by processes such as the rusting of iron in rocks. However, chemical disequilibrium does not *necessarily* indicate life because the imbalance can arise by non-biological processes. Methane on Mars is evidence for chemical disequilibrium but non-biological explanations can account for it.

Nonetheless, detecting the spectral signature of chemical disequilibrium in the light from an extrasolar planet — namely ozone (a proxy for oxygen), CO_2, H_2O, and methane — would make a prima facie case for life. The major problem is that in visible light, the glare of a star outshines its planet 10 billion-fold. The magnitude of the contrast can be reduced to "only" 10 million-fold by observing in the infrared because planets radiate most of their energy at infrared wavelengths.

Going to the limit

Although life is far more adaptable than anyone suspected a few decades ago, it still has definite limits. Temperature is arguably the most important. Biochemical reactions cannot happen in a frozen state. This imposes a lower bound on the temperature at which growth and reproduction can occur. (Survival in suspended animation, however, is possible at much lower temperatures.) At the other extreme, chemical bonds break and biological molecules fall apart at high temperatures.

The ability of organisms to adapt is also a severe constraint. Having adapted to become fit for one environment (for example, high temperature), an organism has a reduced capacity to diversify into another environment (for example, low temperature). This idea, drawn from evolutionary theory, has been confirmed directly by experiments on bacteria. It implies planets will not be habitable where wide swings in conditions continually occur over short evolutionary timescales. Basically, organisms can't keep up.

So, in the end, what are life's limits? We don't know precisely, because our experience involves only terrestrial organisms. Yet our single example of biology provides a lever to help us look for life elsewhere in the universe. If there are alien life-forms, they cannot defy thermodynamics or Darwinian evolution — but we should expect to be surprised. A

See some of the earliest fossil traces of life on Earth at www.astronomy.com/toc

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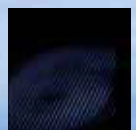

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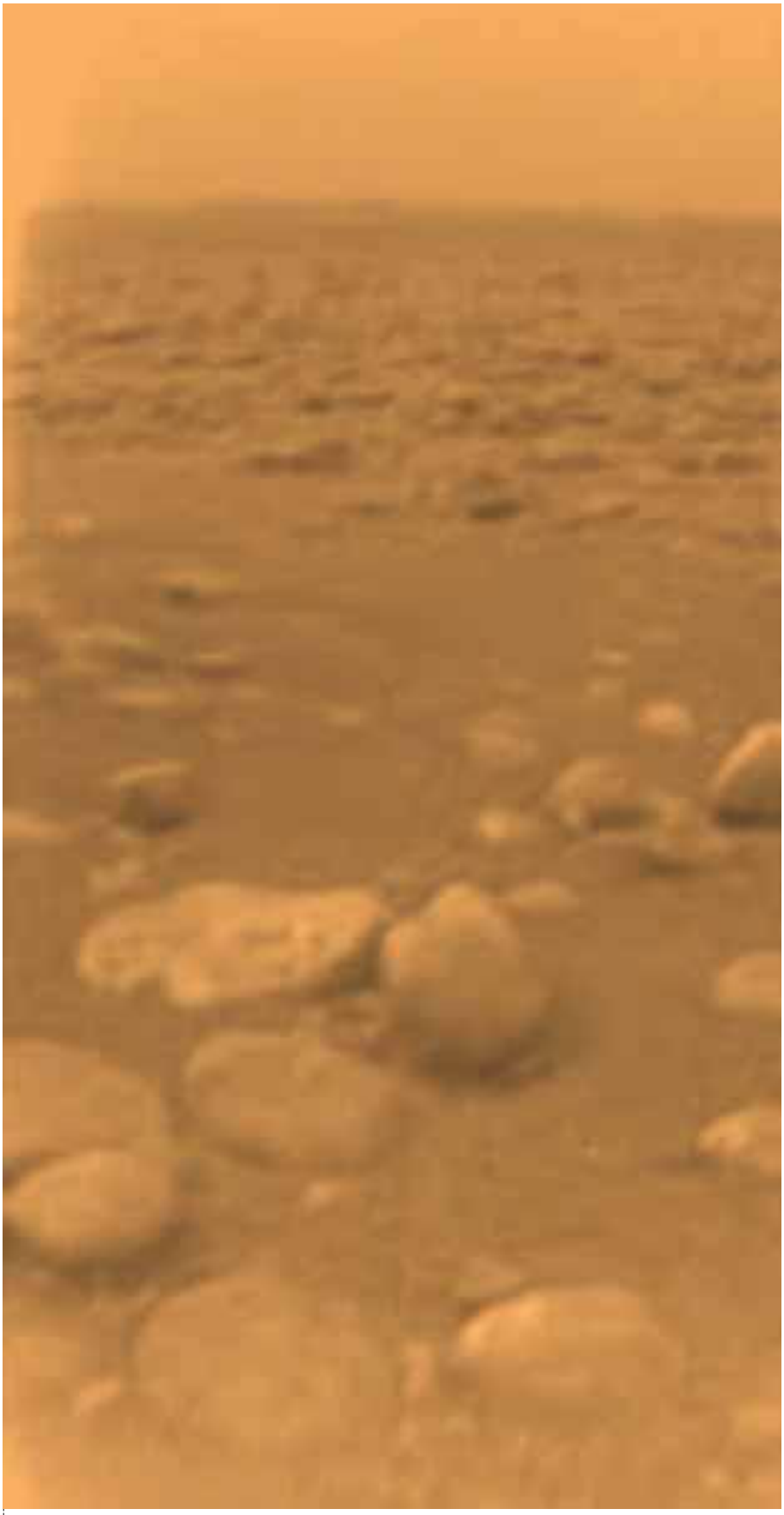
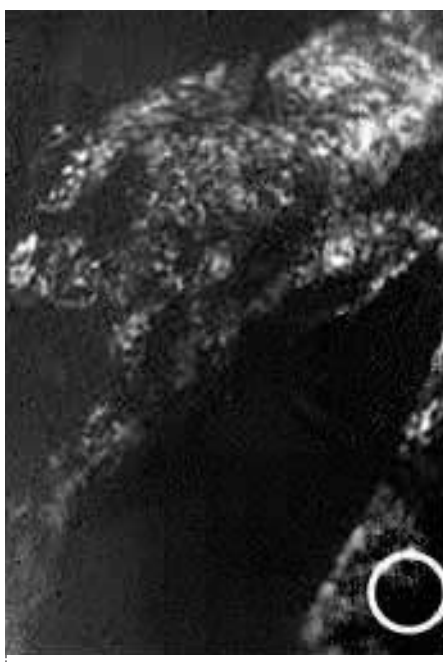
Titan TOU

The Huygens spacecraft plummeted through Titan's atmosphere and landed on a muddy plain January 14, marking the first time humans had landed a spacecraft on a moon other than Earth's. The robotic probe sent 350 photos and reams of other data back to thousands of eager scientists and millions of delighted people.



ICE BLOCKS AND PEBBLES eroded by flowing liquid scatter to the horizon in this true-color view of Titan's surface. The two rock-like objects just below center measure 6 inches (left) and 1.5 inches (right) across and lie 33 inches from Huygens. ESA/NASA/UNIVERSITY OF ARIZONA



HUYGENS TOUCHED DOWN near a dark region that appears to be a lake at least occasionally filled with liquid methane. The white circle at lower right encompasses the science team's initial best-guess of the probe's landing site. ESA/NASA/UNIVERSITY OF ARIZONA

Drainage channels and intermittent methane lakes dot the surface of Saturn's moon Titan. /// BY RICHARD TALCOTT

UCHDOWN

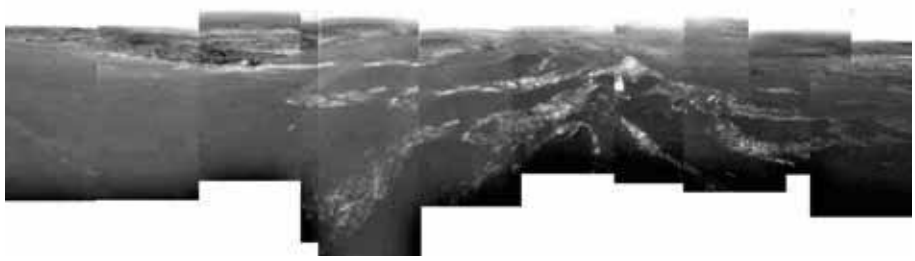
After a 7-year, 2.25-billion-mile journey, Huygens' legacy rested on a few hours and a few hundred miles. For 2 hours and 28 minutes, the craft descended through the thick, haze-choked atmosphere of Titan, a giant moon 3,200 miles wide. It continuously sampled the air for temperatures, pressures, densities, and wind speeds. A camera snapped panoramic images of the moon's surface, revealing an elevated region with a network of drainage channels. Scientists say liquid methane periodically flows through these channels and empties into a flat, dark lake bed.

Huygens touched down not with a thud or a splash, but with a splat — in the equivalent of mud. From its vantage point, the probe peered out over an icy, rock-strewn landscape bathed in orange twilight. Despite the numbing cold — the temperature dipped to –291° Fahrenheit — Huygens survived for 3 hours on the surface.

"This is an historic event," says European Space Agency (ESA) science chief David Southwood. "The torch has now been passed from the engineers who delivered the probe to the scientists who will evaluate the data." Every one of those scientists realizes it will take months or, more likely, years to analyze fully the few hours' worth of data Huygens collected.

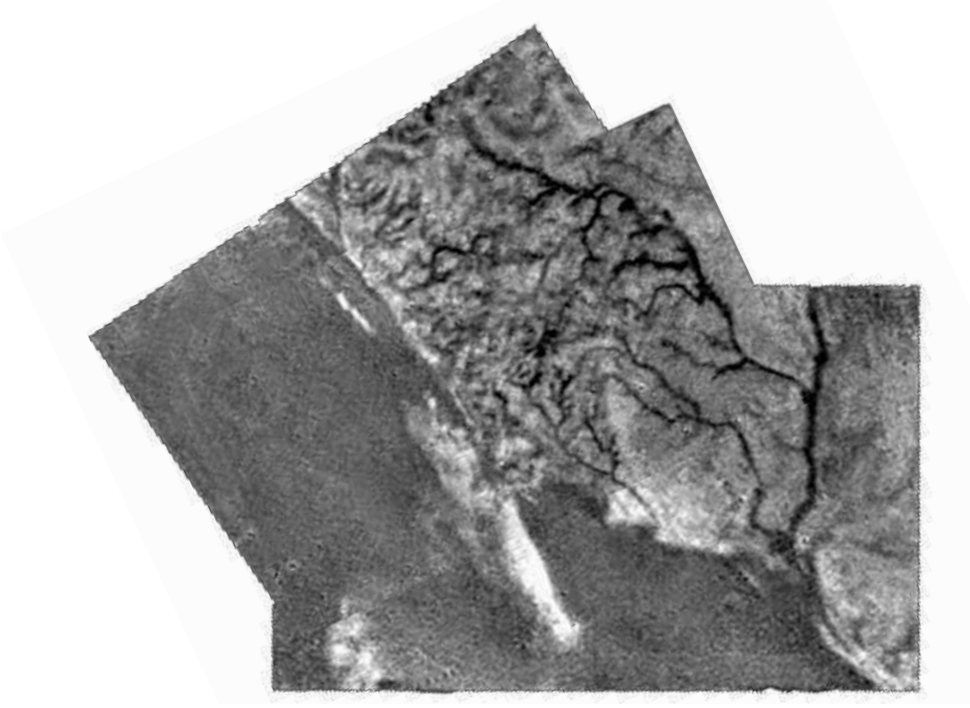
The final leg

The Huygens descent and landing marks the crowning achievement so far for the



HUYGENS CAPTURED A 360° PANORAMA from 5 miles up, revealing a boundary between light and dark areas. Scientists think the white streaks, which did not appear from higher altitudes, could be ground fog consisting of methane or ethane. ESA/NASA/UNIVERSITY OF ARIZONA

THIS COLOR COMPOSITE shows much the same area as the black-and-white panorama above. Titan is quite dark — the moon's hazy atmosphere and large distance from the Sun make the surface just 0.1 percent as bright as Earth's surface. ESA/NASA/UNIVERSITY OF ARIZONA



A MIGHTY RIVER CHANNEL fed by numerous smaller streams flows off a lighter-colored ridge into a dark basin that occasionally fills with liquid methane. The images used to make this composite were taken from an altitude of 5 miles and show details as small as 65 feet across. ESA/NASA/UNIVERSITY OF ARIZONA

Cassini/Huygens mission. NASA's Cassini spacecraft has been observing Saturn, its rings, and its moons since going into orbit around the ringed planet June 30, 2004.

ESA's 700-pound Huygens probe piggybacked on the Cassini spacecraft until December 24/25. That's when Cassini triggered springs that sent Huygens on its way.

Richard Talcott *is a senior editor of* Astronomy.

The 3-week, 2.5-million-mile approach to Titan proved uneventful. Things changed in a hurry as Huygens neared the moon. A system of alarm clocks awakened the slumbering spacecraft a few hours before it hit the atmosphere's fringe at an altitude of 790 miles above the surface.

During the first 3 minutes in the atmosphere, friction with the air slowed Huygens from 11,200 mph to just 870 mph. In the same period, the temperature of the heat shield rose to more than 3,000° F. A small parachute then opened. Its sole purpose was to jettison the probe's rear cover. With the cover gone, the main parachute immediately unfurled and slowed the spacecraft even further.

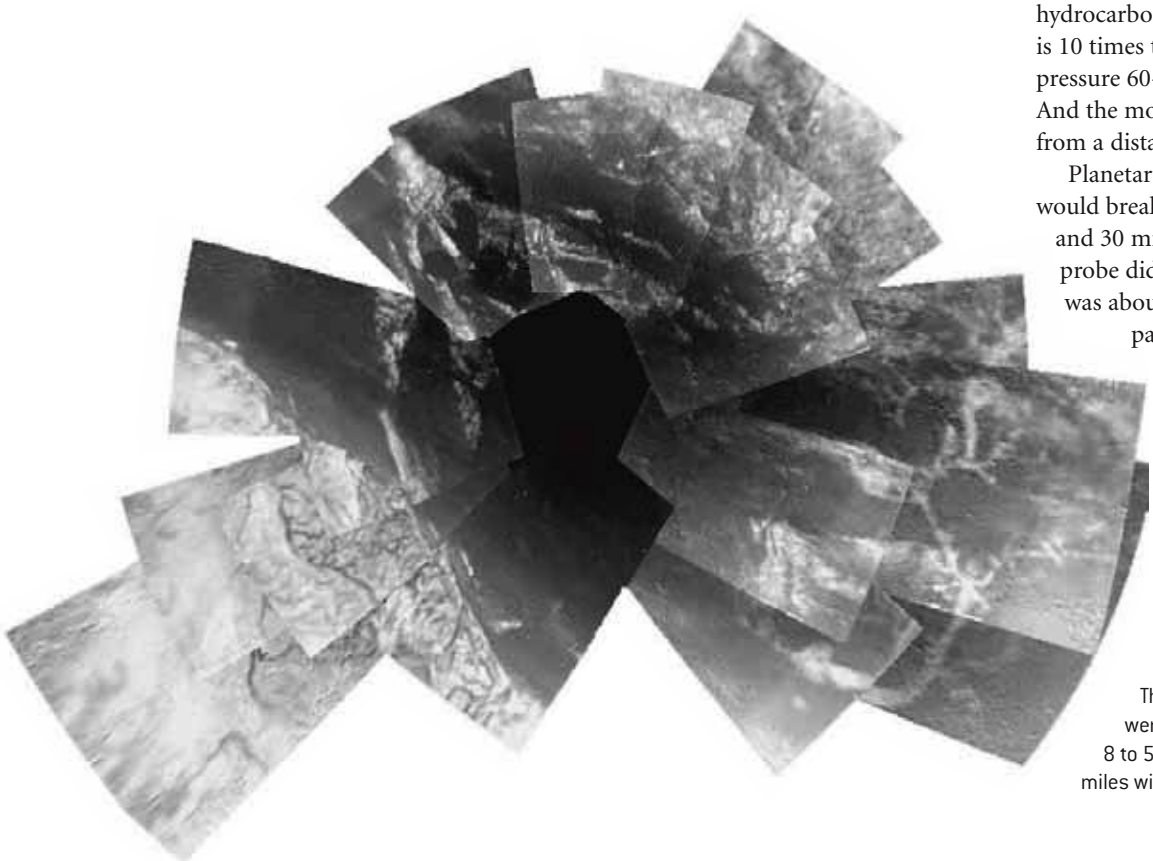
At an altitude of about 100 miles — and less than a minute after the main chute deployed — the six science instruments aboard got their first looks and sniffs of the environment. Huygens remained under the 27-foot-wide main parachute for 14 minutes, until reaching an altitude of 75 miles. The probe then discarded the main chute and deployed a smaller drogue chute 10 feet in diameter. The main chute would have kept Huygens aloft too long, perhaps draining the batteries before landing.

On the way down

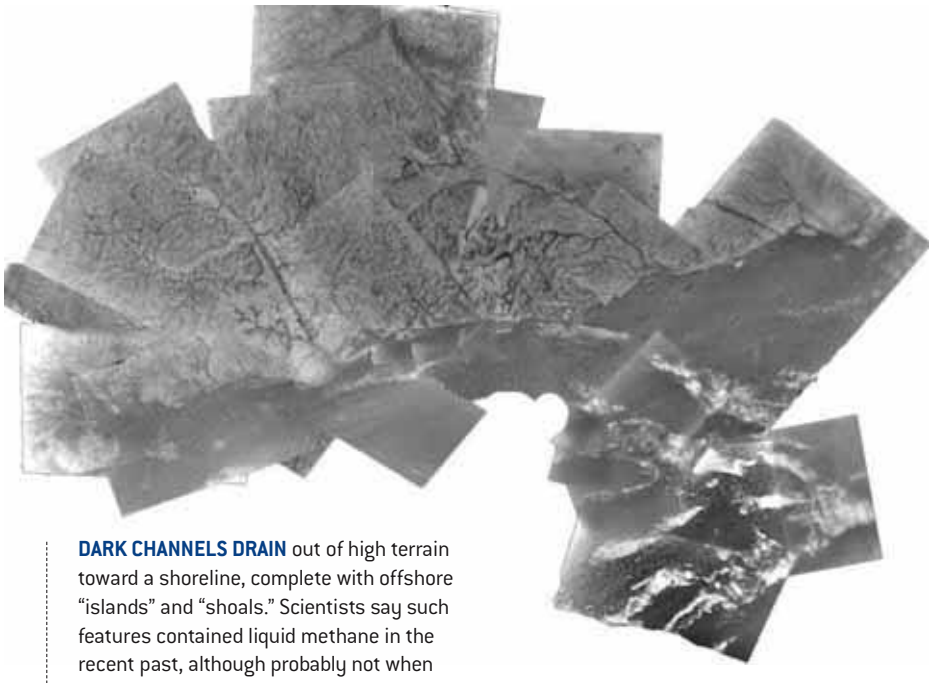
"The ride was bumpier than we thought it would be," says Martin Tomasko of the University of Arizona, who leads the Descent Imager/Spectral Radiometer (DISR) team. In the upper atmosphere, Huygens rocked back and forth as much as 20°. As it descended, the rocking died down and the probe stabilized, swinging less than 3°.

Titan's atmosphere consists mostly of nitrogen — like Earth's — with small amounts of methane, ethane, and other hydrocarbons. But the moon's atmosphere is 10 times thicker and exerts a surface pressure 60-percent greater than Earth's. And the most obvious feature, at least from a distance, is the ubiquitous haze.

Planetary scientists expected Huygens would break through the haze between 45 and 30 miles above the surface. Yet, the probe didn't start to emerge until it was about 20 miles high. Huygens later passed through methane clouds at an altitude of a little more than 10 miles. During the last part of the descent, the concentration of methane increased steadily all the way to the surface.



AS HUYGENS SPUN slowly during its descent, its cameras built up panoramic views of the surface. The 30 images in this composite were taken at altitudes ranging from 8 to 5 miles and cover an area nearly 20 miles wide. ESA/NASA/UNIVERSITY OF ARIZONA



DARK CHANNELS DRAIN out of high terrain toward a shoreline, complete with offshore "islands" and "shoals." Scientists say such features contained liquid methane in the recent past, although probably not when Huygens landed. ESA/NASA/UNIVERSITY OF ARIZONA

Channels and lakes

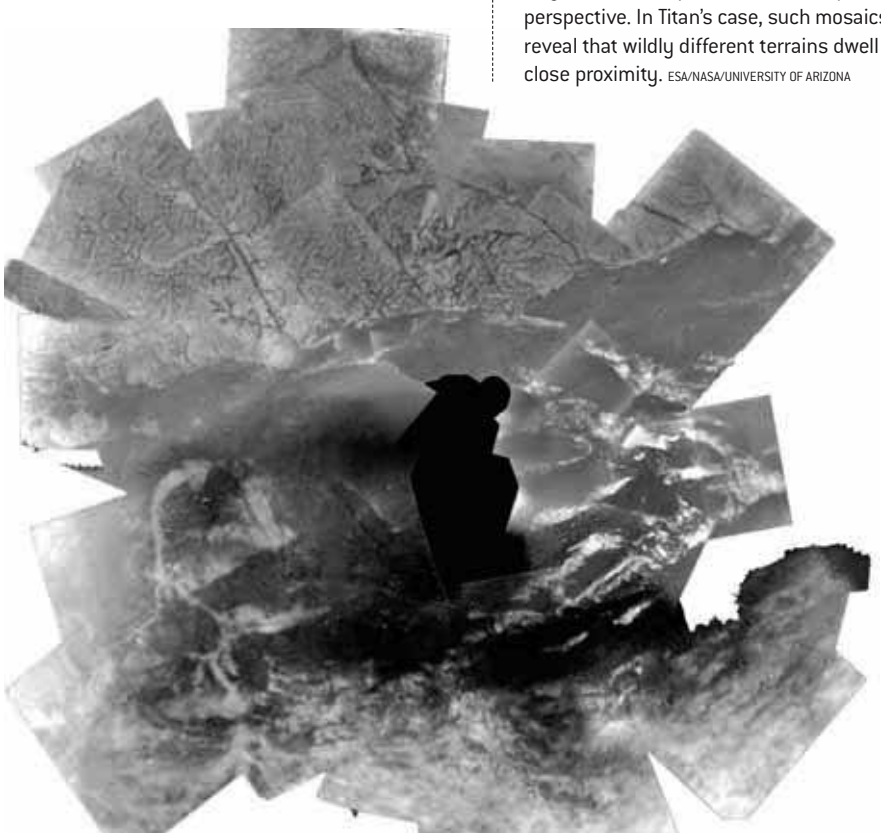
Scientists who hoped the DISR images would show spectacular details weren't disappointed. DISR comprised three camera systems: a high-resolution imager pointing nearly straight down, a medium-resolution imager directed about 30° from straight down, and a low-resolution imager that pointed sideways.

The images reveal a complex surface of light and dark areas with white streaks that appear to be low-lying methane or ethane fog. One area in particular stands out: A light-colored, elevated region not far from the landing site displays dark, sinuous channels that funnel toward a large, flat basin with a shoreline.

"It's impossible to resist the speculation that we are seeing drainage channels or some part of a shoreline," says Tomasko. "We don't know if there is still some liquid [in the channels or lake] or if it's drained away into the surface."

Any liquid on or below Titan's surface could not be water. At a temperature of

STITCHING TOGETHER MOSAICS allows planetary scientists to put entire landscapes into perspective. In Titan's case, such mosaics reveal that wildly different terrains dwell in close proximity. ESA/NASA/UNIVERSITY OF ARIZONA



/// THE ICE CLIFFS OF DIONE

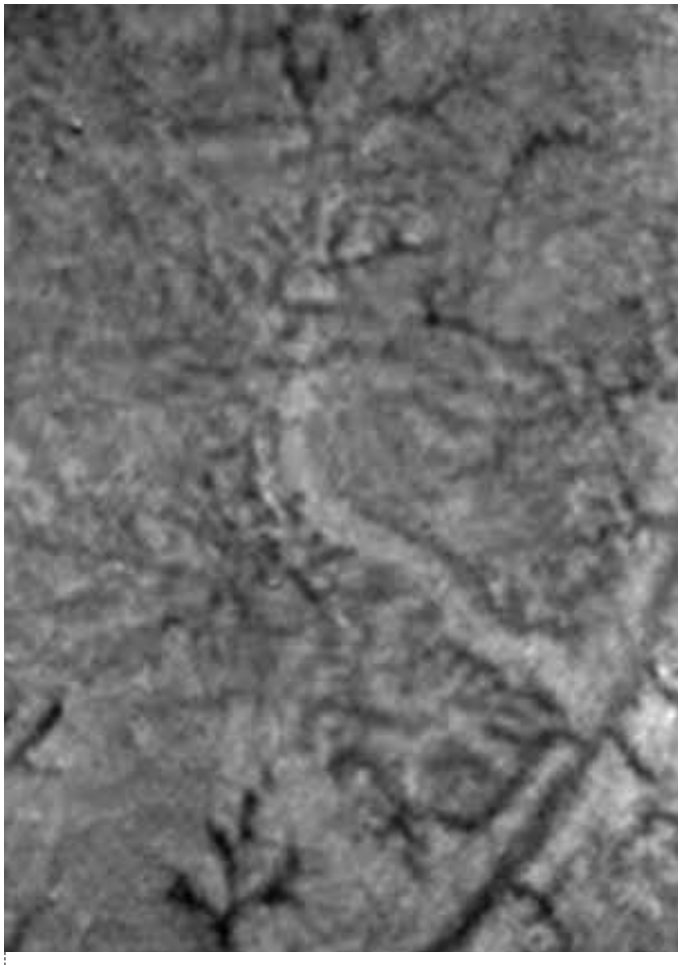
Titan always garners star billing when the subject of Saturn's moons comes up. Not that there's anything wrong with that. After all, it's bigger than the planets Mercury or Pluto, and it's the only moon in the solar system with a significant atmosphere. The existence of liquids on the surface doesn't hurt Titan's cachet either.

But Saturn has six more-modest-size moons the Cassini orbiter will target repeatedly during its 4-year mission. On December 14, the spacecraft flew within 45,000 miles of Dione, an icy moon 696 miles wide. Cassini was half as far away as the Voyager spacecraft came in the early 1980s, so the best Cassini images are about twice as sharp as any seen before.

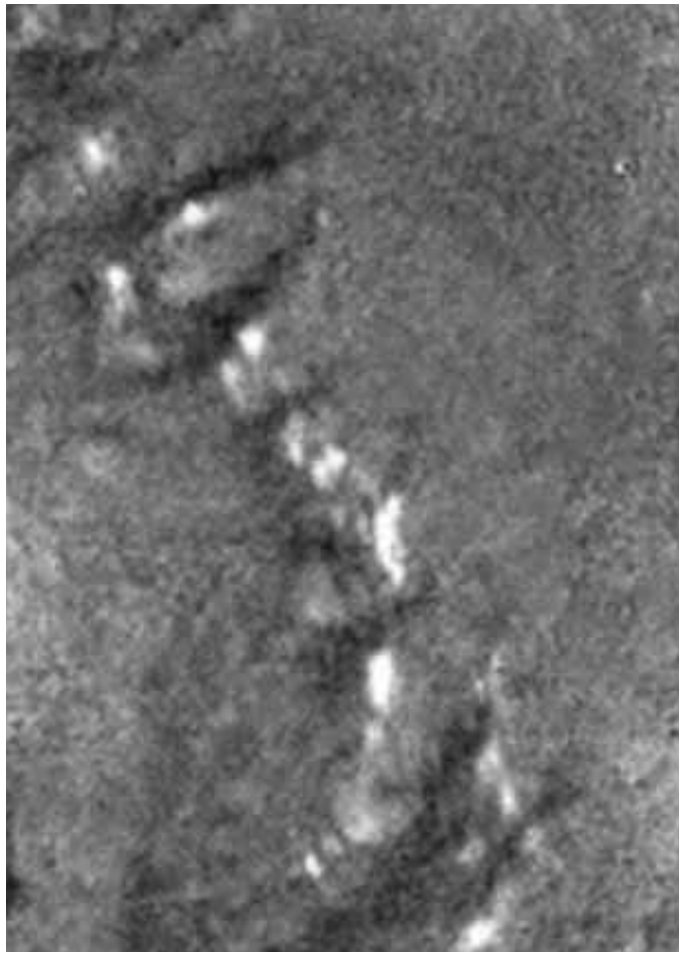
The new images reveal a heavily cratered world with surface fractures that create a complex, braided structure. Planetary scientists have been intrigued by the wispy braids ever since Voyager first saw them. Researchers had suspected they were thick ice deposits, but the sharper Cassini images show the markings are bright cliffs of ice apparently formed by tectonic processes.

WISPY TERRAIN BLANKETS much of Dione. Cassini shows this terrain to be bright ice cliffs created by tectonic fractures, not thick ice deposits as previously thought. NASA/JPL/SSI

"This is one of the most surprising results of the mission so far," says Cassini imaging team leader Carolyn Porco of the Space Science Institute in Boulder, Colorado. "It just wasn't what we expected." Cassini will come much closer to Dione in October 2005. Skimming within 300 miles of the moon's surface, the spacecraft will produce images with a resolution more than 100 times better than during the December flyby. New discoveries no doubt will excite scientists then while raising a host of new questions. — *R. T.*



SHORT, DARK CHANNELS likely formed by "springs" of liquid methane. The bright streak may be water ice oozing to the surface. ESA/NASA/UNIVERSITY OF ARIZONA



LIQUID APPEARS TO FLOW around bright "islands" in this dark plain. The elevations above and below the islands may be different. ESA/NASA/UNIVERSITY OF ARIZONA

–291° F, water freezes as hard as rock. But the methane detected in the atmosphere would be a liquid on the surface.

Tomasko says methane condenses out of the atmosphere and rains on the surface, bringing with it some of the organic haze that shrouds the world. The rain washes this dark material off the highlands into the drainage channels. The imaging team also found evidence of methane springs on the surface.

A muddy splat

Two hours and 28 minutes after entering Titan's atmosphere, Huygens touched down at about 10 mph. "I think the biggest surprise is that we survived landing and that we lasted so long," says DISR team member Charles See of the University of Arizona. "That landing was a lot friendlier than we anticipated."

The Surface Science Package (SSP) included an instrument that penetrated the surface to a depth of about 6 inches. The consistency resembles that of wet sand or clay, with a thin, solid crust on top. The surface consists mainly of dirty water ice and hydrocarbon ice, and is darker than scientists expected. Heat generated by the spacecraft warmed the soil and apparently boiled some of the liquid methane just below the surface. Two sets of instruments detected bursts of this methane gas.

Images of the horizon show lots of rocks, probably made of water ice, ranging from pebble-size to fist-size. The smooth, rounded rocks appear eroded, suggesting Huygens landed next to a channel that, at some point in the recent past, contained flowing liquid methane.

A nearly flawless mission

Huygens sent all of its data to the Cassini orbiter, which was flying nearly 40,000 miles overhead. Cassini then relayed the precious information to Earth. SSP team leader John Zarnecki of the Open University in England summed it up for most when he said: "All the effort our team put into writing software to fill in data gaps was totally wasted."

One small glitch did show up, however. Huygens had two communications channels open to Cassini, but only one of them worked. The problem arose because of a software error on Cassini — a switch was not set to "on." ESA official Jacques Louet says ESA sent improper instructions to NASA's Jet Propulsion Laboratory.

Fortunately, the two channels were sending essentially the same information. (The probe's designers built in a lot of redundancy to head off potential problems.) Of the six experiments, only two were affected: the DISR and the Doppler Wind Experiment (DWE).

The imaging team tried to send a total of 700 images back — 350 through each channel. So, they received 350 images and lost 350. But the alternative would have been to send the same 350 images through both channels, which would have left them with 350 total images. Although the total number of images received on Earth

remained the same, the lost images means the team will end up with some holes in its panoramic mosaics.

The DWE data was a case of bad news/good news. The bad: All the data sent to Cassini was lost. The good: Earth-based observations can reclaim them. The experiment was designed to measure vertical wind speeds in Titan's atmosphere. As wind buffeted the probe, the Doppler effect caused the radio signal's frequency to change slightly.

Although Cassini did not receive the signal, a network of 18 radio telescopes in Australia, Asia, North America, and Europe did. So, scientists eventually will be able to piece together the science.

The tantalizing results reported here represent only a week's worth of reflection by mission scientists, many of whom were operating on little sleep. Deeper insights will come in the months ahead. But there is little question Huygens looks out over a vast, occasional sea. The scenic vista is an appropriate resting place for a space probe that opened our eyes to a new world. A

A gallery of the latest Huygens and Cassini images is at www.astronomy.com/toc

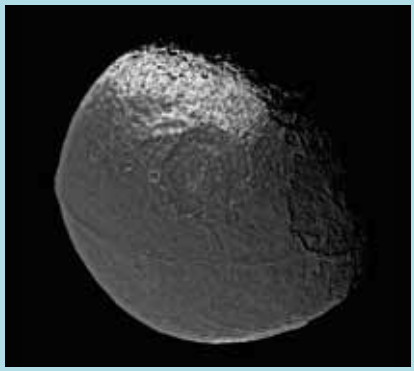
/// IAPETUS' TWO-FACED DEMEANOR

The Cassini orbiter wrapped up 2004 with a flyby of Saturn's outermost large moon, Iapetus. With a diameter of 892 miles, Iapetus is the ringed planet's third largest moon. In terms of strangeness, however, it ranks right up there with Titan.

Iapetus has the oddest brightness distribution of any object in the solar system. One hemisphere reflects light like newly fallen snow, while the other half appears as dark as freshly laid asphalt. Icy moons like Iapetus tend to reflect lots of light, so planetary scientists are most intrigued by what the dark material is.

Cassini came within 77,000 miles of Iapetus December 31, providing scientists with their closest look ever at the moon's dark side. Cassini found craters everywhere, with those in the moon's northern regions having bright crater walls on the sides facing the pole.

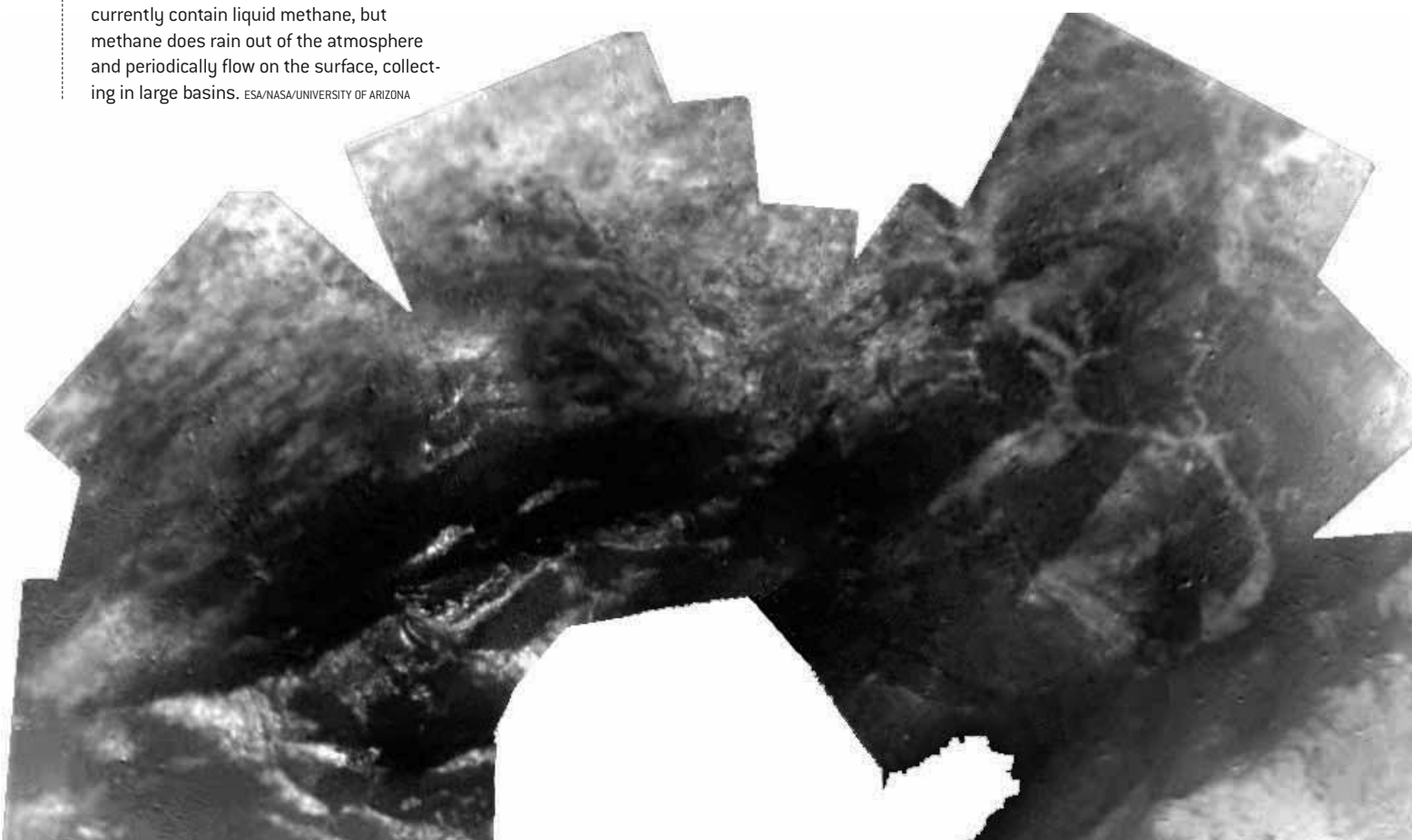
But Cassini's key discovery was finding one of the most striking geological features ever seen on a moon. A long, narrow ridge bisects the entire dark hemisphere of Iapetus. The ridge runs essentially parallel to the moon's equator and measures some 800 miles long by a little more than 10 miles wide.



THE DARK SIDE OF IAPETUS features an 800-mile-long ridge nearly coinciding with the moon's equator. The ridge's mountains rise up to 3 times higher than Mount Everest. NASA/JPL/SSI

In places, huge mountains form the ridge. They stand among the biggest mountains in the solar system, rivaling Olympus Mons on Mars, and some are 3 times higher than Earth's Mount Everest. Scientists have yet to figure out whether the ridge is a compressional feature, like a mountain belt that folded upward, or a surface crack through which material from inside Iapetus erupted. — *R. T.*

IS THAT LIQUID DOWN THERE? Scientists aren't yet willing to claim these dark features currently contain liquid methane, but methane does rain out of the atmosphere and periodically flow on the surface, collecting in large basins. ESA/NASA/UNIVERSITY OF ARIZONA



DARKER than the night

Astronomers are scrambling to figure out galaxies that nearly disappear into the night sky. Yet, these oddballs could outnumber normal galaxies ten to one. /// BY BRUCE DORMINEY

Even on the clearest, darkest night, bright galaxies appear as fuzzy little blobs through the best binoculars. Those fortunate enough to have exceptional naked-eye night vision sometimes can distinguish the luminous glow of the Andromeda Galaxy (M31), our nearest spiral neighbor. But big galaxies like Andromeda and the Milky Way make up only a tiny part of our own Local Group of galaxies and, indeed, of the cosmos as a whole.

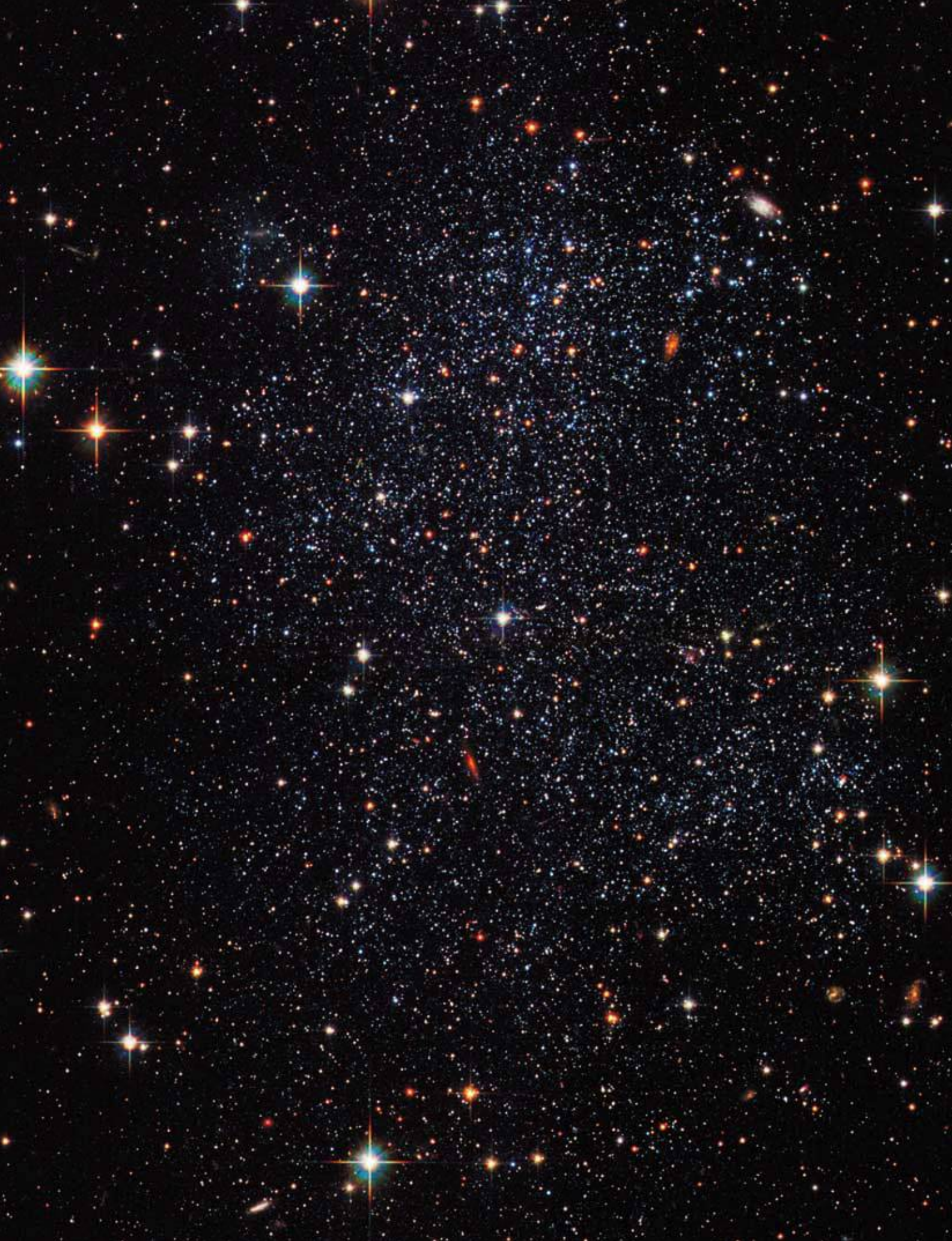
At the limits of our technological prowess in the radio and optical spectra lies a bizarre universe of galaxies that defy theoretical explanation. Some of these oddballs have surface brightnesses 6 magnitudes (250 times) fainter than the background of the night sky. (Surface brightness measures how bright a given area of an object appears.) Although low-surface-brightness (LSB) galaxies have been surveyed and studied for the past 2 decades, they still challenge almost everything astronomers know about galaxy formation, galactic dynamics, and gravitation.

By definition, any diffuse galaxy with a surface brightness about one magnitude fainter than the night-sky background qualifies as an LSB galaxy. Since their discovery in the mid-1980s, more than 3,000 of these objects have been detected and cataloged. They range in size from a small fraction of the Milky Way up to some 10 times the dimensions of our galaxy.

Malin 1, a spiral monster lying behind the Virgo cluster some 1.1 billion light-years from Earth, remains the largest LSB galaxy detected. And although most LSB galaxies are dwarf irregulars, at least several dozen giant LSB spirals approach the size of Malin 1.

Astronomers have likened LSB galaxies to the vanishing Cheshire cat from *Alice's Adventures in Wonderland* because often the only detectable part is the fleeting "grin" from

LOW-SURFACE-BRIGHTNESS GALAXIES typically don't look like much, even when they're nearby. The Sagittarius Dwarf Irregular Galaxy, which fills most of this frame, epitomizes their ephemeral demeanor. NASA, ESA, AND Y. MOMANY (UNIVERSITY OF PADUA)



Antlia Dwarf

ESO

Phoenix Dwarf

NOAO/NSF/AURA

Sextans A

SUBARU TELESCOPE, NAOJ

WLM

NOAO/NSF/AURA

their cores. Their outer regions are as difficult to image as the netherworlds at the fringe of our solar system.

Because most LSB galaxies appear to be young and full of hot, blue stars, they are best observed with wide-field telescopes with detectors sensitive to the blue part of the optical spectrum. Follow-up observations by radio telescopes traditionally involve detecting the telltale emission of neutral atomic hydrogen at a wavelength of 21 centimeters. However, this is time-consuming and allows astronomers a limited view of what's happening in any given LSB galaxy.

It's no wonder that as late as the 1970s, astronomers were influenced by "selection bias" in how they detected and recorded the central surface brightness of galaxies. (Distant galaxies with low surface brightnesses tend to melt into the background, while those with high surface brightnesses appear like stars. This caused astronomers to miss a lot of galaxies.) So when Ken Freeman, an Australian astronomer, wrote a 1970 paper on the correlation between a galaxy's observed central surface brightness and its rate of detection, others ran with the idea. His paper spawned "Freeman's Law," with the axiom that most spiral galaxies appear to have a central surface brightness of about 21.6 magnitudes per square arcsecond.

But in the late 1970s, while measuring the brightnesses of some 20 galaxies culled from the Palomar Observatory Sky Survey, doctoral candidate William Romanishin found spiral galaxies 1.5 to 2 times fainter than what was considered normal. Romanishin, now an astronomer at the University of Oklahoma, had opened the door to the possibility that astronomers had been observationally blindsided by high-surface-brightness objects.

On the trail of Malin 1

By the mid-1980s, David Malin, an astronomer and astrophotographer at the Anglo-Australian Observatory in Siding Spring, Australia, was surveying galaxies in the Virgo cluster, the nearest rich cluster of galaxies, when he discovered Malin 1. He was using the 1.2-meter wide-field UK Schmidt telescope and a photographic technique that came to be called "Malinization."

The technique involves making a copy of the original glass plate using high-contrast film and a diffuse light source, not unlike an X-ray viewbox in a doctor's office. These Malinized films then can be added together photographically to obtain a deeper and more contrasty image. Although CCDs are more efficient than photographic plates, photography still proves useful for detecting large, low-surface-brightness objects.

"Photography has all sorts of irritating problems," says Malin, "but for detecting faint things against the night sky, it's bloody good. So if you see some sort of faint blob there, particularly on more than one picture, then it's real. I came across this rather strange galaxy that had a big, fuzzy nucleus and some clumpy stuff in its outer envelope."

He sent his data to University of Oregon astronomer Greg Bothun, who, at the time, was working on the detection of LSB galaxies with Chris Impey, now an astronomer at the University of Arizona. Bothun remembers using the Arecibo radio telescope

MORE THAN 80 PERCENT of Local Group galaxies qualify as low-surface-brightness dwarf galaxies. The samples on these two pages show they range from bits of near-nothingness to slightly more substantial entities.

to look for the 21-cm signature of neutral hydrogen from Malin's odd-looking galaxy.

He picked up the hydrogen emission and found it to be significantly redshifted thanks to the universe's expansion. Malin 1 was receding from Earth at 15,500 miles (25,000 kilometers) per second, which implied it was much farther away than astronomers had expected. If the distance derived from the velocity was accurate, Malin had stumbled upon a galaxy that, from all appearances, had just begun the business of star formation. Yet, incredibly, this galaxy had a surface brightness of only about 28 magnitudes per square arcsecond.

Astronomers estimate that Malin 1, which is characterized by a large galactic bulge and an active nucleus, is only 3 to 5 billion years old. Thus far, no supernova has been detected in Malin 1 or any of its LSB counterparts.

In normal galaxies, supernovae create the heavier elements that, in turn, help cool the molecular gas that collapses to form stars. Eventually, high-density molecular clouds reach a point where they become gravitationally unstable and start to fragment and form stars. But because LSB galaxies appear to be supernova-free, they contain few heavy elements. So, LSB galaxies like Malin 1 are short on both high-density molecular clouds and busy star-forming regions.

Galaxies full of gas

Although some astronomers dispute the apparent youth of LSB galaxies, as a rule, most of these objects tend to have lots of young, blue stars and hydrogen gas. They also appear to evolve at a much slower rate than higher-density, higher-surface-brightness galaxies like the Milky Way.

By comparison, while the Milky Way already has converted some 90 percent of its gas into stars, LSB galaxies still are sitting on the majority of their neutral hydrogen reserves. It's this neutral hydrogen that radio astronomers observe as a large, extended, low-surface-brightness disk attached to a brighter, central core.

In some cases, 90 percent of an LSB galaxy's gas has yet to be converted into stars. But even though some LSB galaxies have a total gas density less than the theoretical value needed for star formation, they clearly are forming stars.

"Take our Milky Way Galaxy and increase its radius by a factor of 3 while keeping the same number of stars in it," says Bothun, "and you would have a low-surface-brightness galaxy. Star formation shouldn't occur in low-density environments, but we have entire galaxies that have low-density environments brimming with stars. They may become higher-surface-brightness spiral galaxies in the future, but it might take another 5 billion years."

How could such objects form? Galaxies with normal surface brightnesses appear to form through a "bottom-up" scenario in which dwarf galaxies — fueled by a large amount of dark matter in their galactic halos and central cores — continually merge to form larger structures. Recent observations with the Hubble Space Telescope suggest the bulk of the universe's galaxies sprouted this way within the first 6 billion years of the universe's existence.

The unseen dark matter gravitationally attracts neutral hydrogen into a budding galaxy's dense core, causing the whole galaxy structure to spin up due to angular momentum. But just why LSB disks collapse into something 3 to 5 times larger than our own galaxy remains hard to explain.

NOAO/NSF/AURA

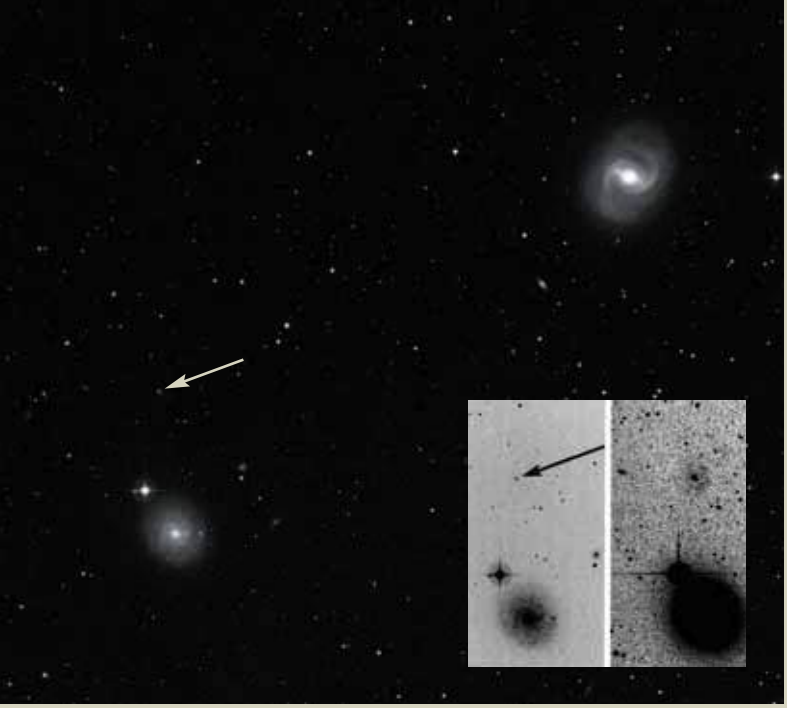
NGC 6822

NOAO/NSF/AURA

Sextans B

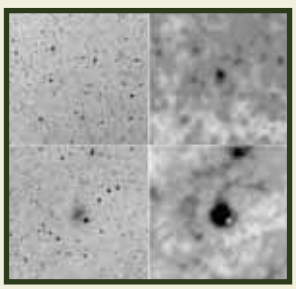
NOAO/NSF/AURA

IC 10



LSB GALAXY MALIN 1 (arrow) is the largest known. It lies well beyond the Virgo cluster and barely appears in this image from the Palomar Observatory Sky Survey. Note the much brighter galaxies NGC 4571 (below Malin 1) and M91 (upper right). INSET: Malin 1 barely appears even in an enhanced image (right). The object, whose surface brightness falls well below that of the night sky, glows dimly north of NGC 4571. DIGITIZED SKY SURVEY

/// TEASING SUBSTANCE OUT OF NEAR-NOTHINGNESS



TWO LOCAL GROUP GALAXIES, Andromeda V (top two images) and Andromeda VI (bottom two), appear weakly in the original Palomar Observatory Sky Survey images (shown at left in each pair). The galaxies show up more clearly once the images are enhanced (shown at right in each pair). DIGITIZED SKY SURVEY

According to normal Newtonian physics, as the radius gets bigger, the rotation velocity of an LSB galaxy should slow. But that's not what astronomers observe. Thus, one explanation for the unexpectedly high velocities found in LSB spirals is that the gravitational influence of hidden dark matter provides these galaxies with a little extra angular momentum.

But even if dark matter spins up these LSB galaxies, at some point, Bothun says, they should become so diffuse they would no longer hold together. The ratio of dark matter to ordinary (baryonic) matter would have to be some 10,000 to one — a configuration he says doesn't exist. He notes the Milky Way tips the scale at 90-percent dark matter to 10-percent baryonic, while Malin 1 is roughly 98-percent dark matter and only 2-percent baryonic.

"We don't really know why galaxies don't fall apart," says Mike Disney, an astrophysicist at Cardiff University in the United Kingdom. He first predicted the existence of diffuse, low-contrast, LSB-like galaxies in 1976. "Until we either find out what dark matter may be made of or map it more clearly than we can now," he adds, "it's just an ad hoc device that's been brought in to fix up a couple of observations."

Yet Stacy McGaugh, an astronomer at the University of Maryland with a longtime interest in galaxy dynamics, says his own optical observations bear out the fact that dark matter and luminous matter are "intimately coupled." However, McGaugh readily acknowledges he doesn't understand how or why dark matter and luminous matter appear to interact so closely if dark matter remains immune to electromagnetic interactions and is influenced solely by gravity.

Stanford University particle physicist Savas Dimopoulos believes dark matter actually may be ordinary matter from a parallel universe or universes gravitationally intertwined with our own. That would explain why dark matter appears to interact only with gravity and may be one reason gravity is a perplexingly weak force in comparison with electromagnetism. "If this dark matter is baryonic, then gravity would leak between two universes, and we would definitely be able to detect that with LISA," says Dimopoulos. LISA, the Laser Interferometer Space Antenna, is a joint mission of NASA and the European Space Agency scheduled for launch in 2011. In theory, it will be sensitive to gravitational radiation from dark matter in such parallel universes.

On the trail of dark dwarfs

Meanwhile, numerical simulations predict that if our universe is dominated by cold dark matter — so large spiral galaxies form in a bottom-up scenario — then some 500 dark-matter-dominated dwarf galaxies should be left over from the Local Group's formation. Thus far, despite extensive surveys in visible light and radio waves, astronomers have detected only about 35 dwarf galaxies. Are the simulations missing something basic and predicting objects that aren't really there, or are hundreds of dark-matter satellites lurking out there in the Local Group that we just haven't been able to detect?

Josh Simon hopes he has found the first of these missing dwarf galaxies. After analyzing 21-cm observations taken at Arecibo, Simon, a doctoral candidate in astronomy at the University of California at Berkeley, believes he and his colleagues may have found the first dwarf dark galaxy. While LSB galaxies always have stars in them, a dark galaxy is a theoretical object made of gas and dark matter but void of stars. And according to theory, astronomers expect most dark galaxies to be dwarfs.

Simon's candidate dark galaxy is a high-velocity cloud (HVC), an object consisting of neutral hydrogen gas and dark matter traveling so fast it seems unlikely to be bound gravitationally to our galaxy. Termed HVC 127–41–330 (the numbers denote its galactic longitude, latitude, and velocity toward the Sun), it measures some 20,000 light-years in diameter and lies some 2.3 million light-years from the Milky Way, between the Andromeda Galaxy and another Local Group spiral, M33.

It's the first HVC clearly not associated with the Milky Way itself. Simon believes this high-velocity cloud is a small, pristine dwarf galaxy with an exceedingly low density that was left over from the Local Group's formation.

Bruce Dorminey *is a France-based science writer and author of* Distant Wanderers: The Search for Planets Beyond the Solar System *(Springer-Verlag).*

In the Local Group, hundreds of HVCs superficially look like this one. But this double-lobed, oval object is the only one astronomers have observed rotating. This rotation allowed Simon to measure the object's mass. He found it contains more than 4 times as much mass as its observed neutral hydrogen can account for, implying dark matter dominates the cloud. Simon hopes to observe this HVC with a 4-m optical telescope to confirm it contains no stars, but he acknowledges "it's difficult to understand how these things could have been sitting out there for billions of years without ever forming stars."

There even may be some subset of dark galaxies containing what Disney terms "frozen" disks. Such galaxies would have a disk of hydrogen held together by dark matter that, for some reason, had not formed stars. If all the galaxy's neutral hydrogen had fallen into its lowest energy state, then it couldn't emit 21-cm radiation, and it would be nearly impossible to detect. But Disney believes there may be another way to detect such frozen galaxies: Their spectral fingerprints might show up as foreground noise in spectra of distant quasars.

"This inert hydrogen is capable of absorbing radiation from a background quasar," says Disney. "So you'll see a little nick in its spectrum. We find that when we look at quasars, they contain about 200 times as many nicks in them as we can explain as a result of ordinary galaxies standing between us and the quasars."

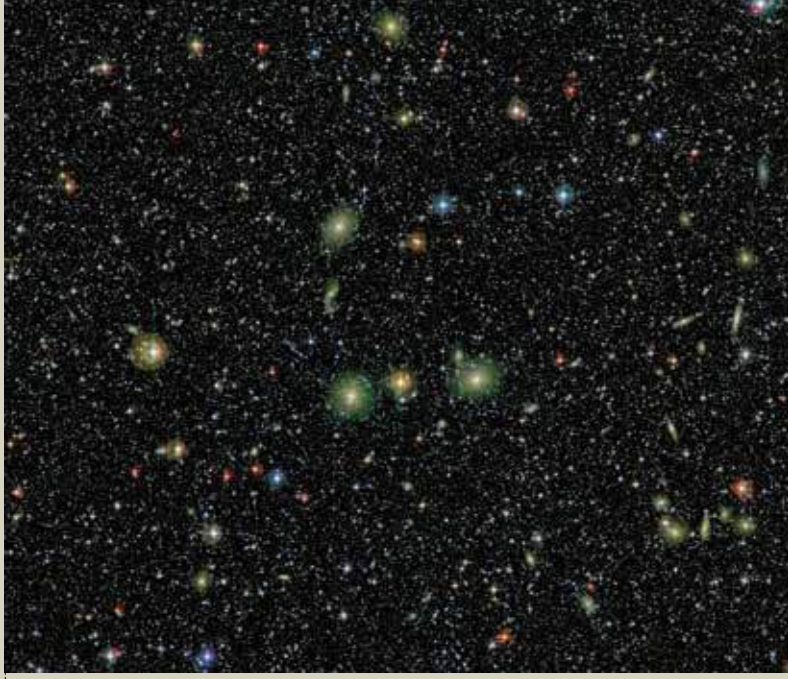
Even so, the future of detecting LSB galaxies lies in wide-field telescopes like the European Southern Observatory's 2.5-m VLT Survey Telescope and 4-m Visible and Infrared Survey Telescope for Astronomy. Both will sit atop Cerro Paranal in Chile's Atacama Desert, near the current site of the Very Large Telescope. Due to see first light in 2004 and 2007, respectively, both instruments will help shed light on Bothun's gut-level hunch that LSB galaxies could make up 90 percent of the galaxies in the universe.

Then, by the end of 2010, a consortium of institutions that includes the National Optical Astronomy Observatories, the University of Arizona, and the University of Washington, hopes to see operation of the $120-million Large-aperture Synoptic Survey Telescope (LSST). An 8.4-m wide-field telescope, it will be capable of imaging almost the whole sky in a period of several nights.

"The LSST will marry large aperture and wide field in an unprecedented way," says LSST systems scientist Chris Stubbs, an astronomer at the Harvard-Smithsonian Center for Astrophysics. In half the time of the Sloan Digital Sky Survey, the LSST will image objects 5 times fainter, covering the sky every few days either to look at what's changed or to build a very deep composite image of a single LSB galaxy.

Ultimately, such new technology may allow astronomers to map the low-density local universe in greater detail than ever before. As observations with NASA's Chandra X-ray Observatory have recently pointed out, rivers of unfathomably hot gas trace an intergalactic web of dark matter within the Local Group of galaxies. It's part of a low-density cosmic web that appears to run along extended dark-matter filaments within clusters and superclusters of galaxies. Astronomers hope future observations will enable them to differentiate and characterize LSB galaxies and their connection to the low-density fabric of the cosmic web itself. A

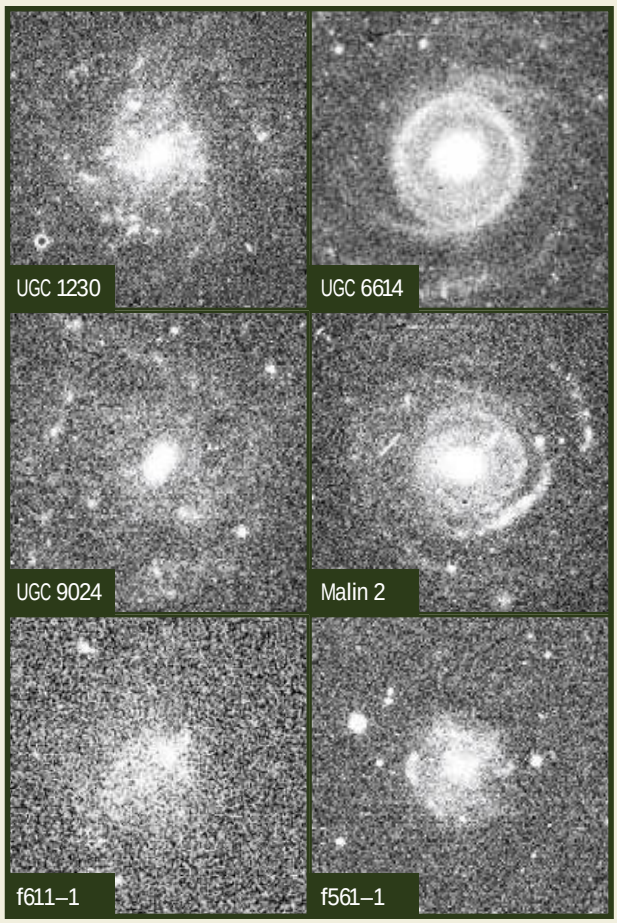
To see how LSB galaxies dominate the Local Group, and learn where to find them in the night sky, visit www.astronomy.com/toc



MASSIVE GALAXY CLUSTER ACO 3627 lies 250 million light-years from Earth. Hundreds of high-surface-brightness galaxies can be seen in the cluster, but most LSB galaxies would be invisible at this enormous distance. ESO

/// LSB GALAXIES IN THE DISTANT UNIVERSE

PERHAPS 90 PERCENT OF GALAXIES in the cosmos are LSB galaxies, although astronomers have found only around 3,000 so far. This sampling shows they come in both spiral and elliptical shapes.



ALL IMAGES: GREG BOTHUN (UNIVERSITY OF OREGON)

BY MARTIN RATCLIFFE AND ALISTER LING

APRIL 05

Complementing the Moon's packed schedule of events this month, several planets, comets, asteroids, and galaxies prepare to strut their stuff.

A solar eclipse rarity

The Moon's shadow sweeps eastward across our planet April 8, bringing a rare hybrid solar eclipse to Earth's surface. Along a narrow swath of the Pacific Ocean, the Moon completely covers the Sun for up to 42 seconds. Along a similarly constricted path through Panama, Colombia, and Venezuela, a spectacular "Ring of Fire" will impress observers.

Elsewhere across southern North America and western South America, the Sun appears partially eclipsed. The Moon's shadow makes landfall on North America's west coast in mid-afternoon and leaves Earth off the Atlantic coast at sunset. Amateur astronomers will be out in force to show the eclipse to the general public — ask at the nearest planetarium or science center.

As always, exercise caution when viewing a partial solar eclipse. Never look directly at the Sun with your eyes or through binoculars or a telescope without a proper solar filter. You risk partial or total blindness. You can purchase a safe filter from one of the companies that advertises in *Astronomy* or at your local science center.

Jupiter continues to impress observers with its display of cloud belts, white ovals, and festoons. The biggest planet in the solar system reaches an important milestone — opposition — April 3. Jupiter then lies opposite the Sun in our sky, rising near sunset and setting near sunrise. For the best views through a telescope, wait until mid-evening for Jupiter to climb above the turbulence in the lower levels of our atmosphere. All four Galilean moons line up on one side of Jupiter the evenings of March 31, April 7, and April 21.

A PARTIAL SOLAR ECLIPSE awaits observers throughout southern North America and western South America the afternoon of April 8. JOHN R. FOSTER

As wonderful as the views of Saturn sent to us by the Cassini spacecraft are, seeing Saturn with your own eyes through a telescope can be more rewarding. Take a close look at the shadow of Saturn's globe falling on the rings behind the planet. Week by week during April, the shadow appears to grow because Earth's orbit carries us a little to the side, giving us a slightly different perspective on the ringed world.

Mars lingers in the morning sky, where it appears fairly inconspicuous to the naked eye and totally unimpressive through a telescope. Better views await observers this summer and autumn.

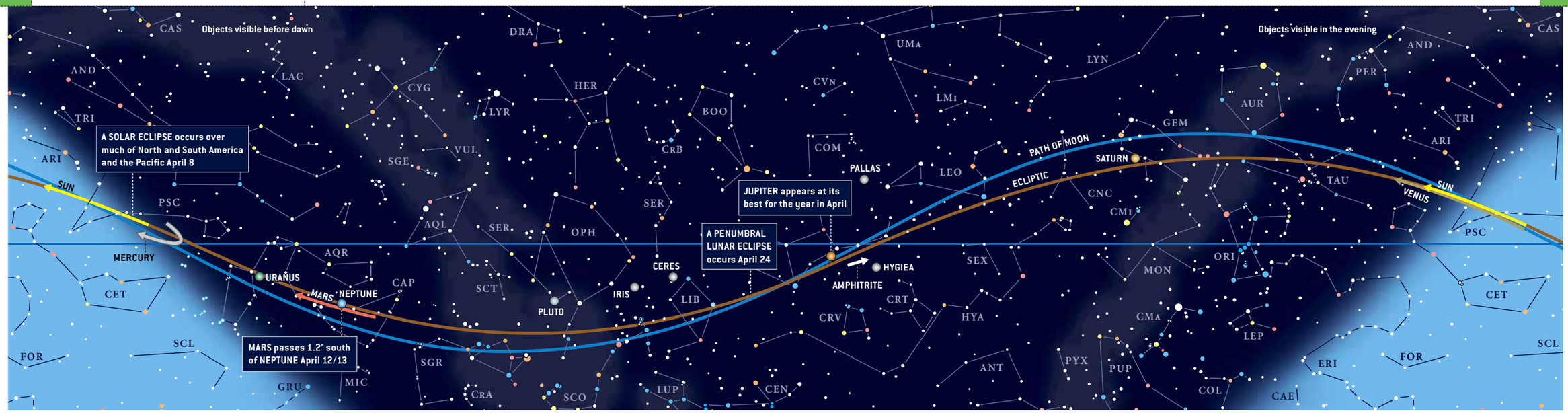
Comet C/2004 Q2 (Machholz) remains a lovely sight in binoculars from a dark-sky site. It stays visible all night, circling the pole as it steps over the Dragon's tail and enters the den of the Great Bear. Away from city lights, the realm of galaxies in Virgo beckons. As if trying to show the way, asteroid Pallas glows just one or two fields away from several galaxies. It is well within reach of the smallest telescope.

A second eclipse occurs this month, but it will be subtle. The Moon passes through Earth's lighter shadow, called the penumbra, the morning of April 24. Sharp-eyed observers will see the Moon's northern half take on a yellowish shade as it sets near sunrise.

As it traverses the sky, the Moon creates other exceptional events. It sneaks into the western evening sky as a hard-to-see, day-old crescent April 9. The following night, it appears as a gorgeous bright arc, with the dark side filled with blue-gray earthshine. Don't miss the splendid binocular sight when the Moon pairs up with the Pleiades star cluster April 11. Cresting above Saturn on the 15th, the Moon then covers up Jupiter for people in southern Africa a week later. Europeans see a similar occultation of the red supergiant star Antares the morning of April 27.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



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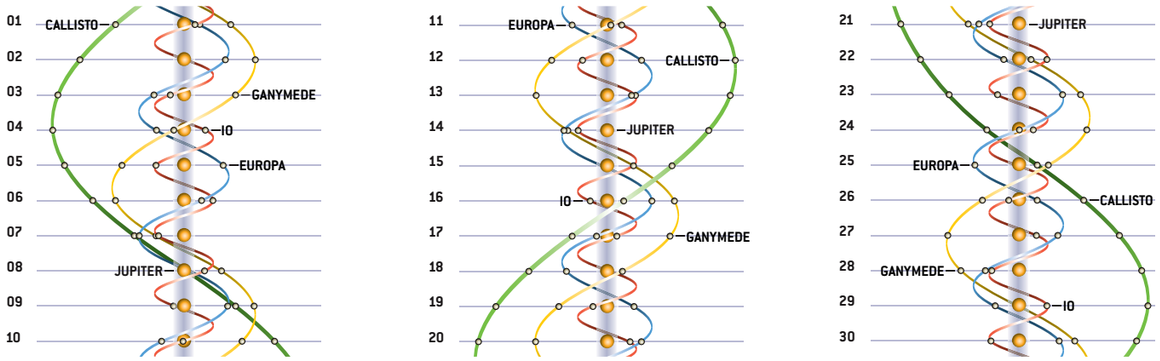
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

[30] [29] [28] [27] [26] [25] [24] [23] [22] [21] [20] [19] [18] [17] [16] [15] [14] [13] [12] [11] [10] [09] [08]

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	April 15	April 30	April 15	April 15	April 15	April 15	April 15	April 15	April 15
Magnitude	0.9	0.3	–3.8	0.8	–2.5	0.1	5.9	7.9	13.9
Angular Size	9.9"	7.5"	9.7"	6.2"	44.1"	18.3"	3.4"	2.2"	0.1"
Illumination	24%	50%	100%	88%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.682	0.895	1.722	1.499	4.473	9.088	20.750	30.428	30.418
Distance (AU) from Sun	0.462	0.456	0.724	1.439	5.457	9.070	20.063	30.064	30.937
Right Ascension (2000.0)	0h08.9m	0h52.1m	1h48.7m	21h24.4m	12h48.3m	7h30.2m	22h44.5m	21h18.7m	17h36.8m
Declination (2000.0)	–0°08'	2°27'	10°10'	–16°38'	–3°28'	21°59'	–8°47'	–15°47'	–15°04'

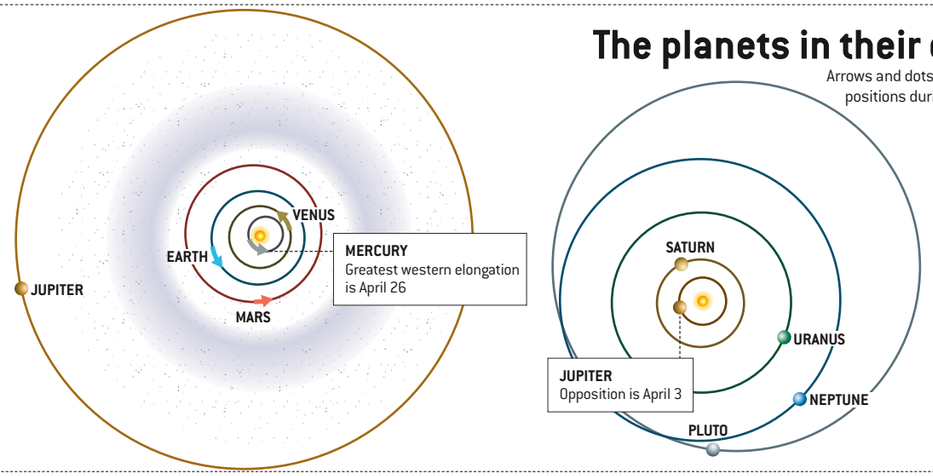
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on date shown. South is at top to match the view in a telescope.



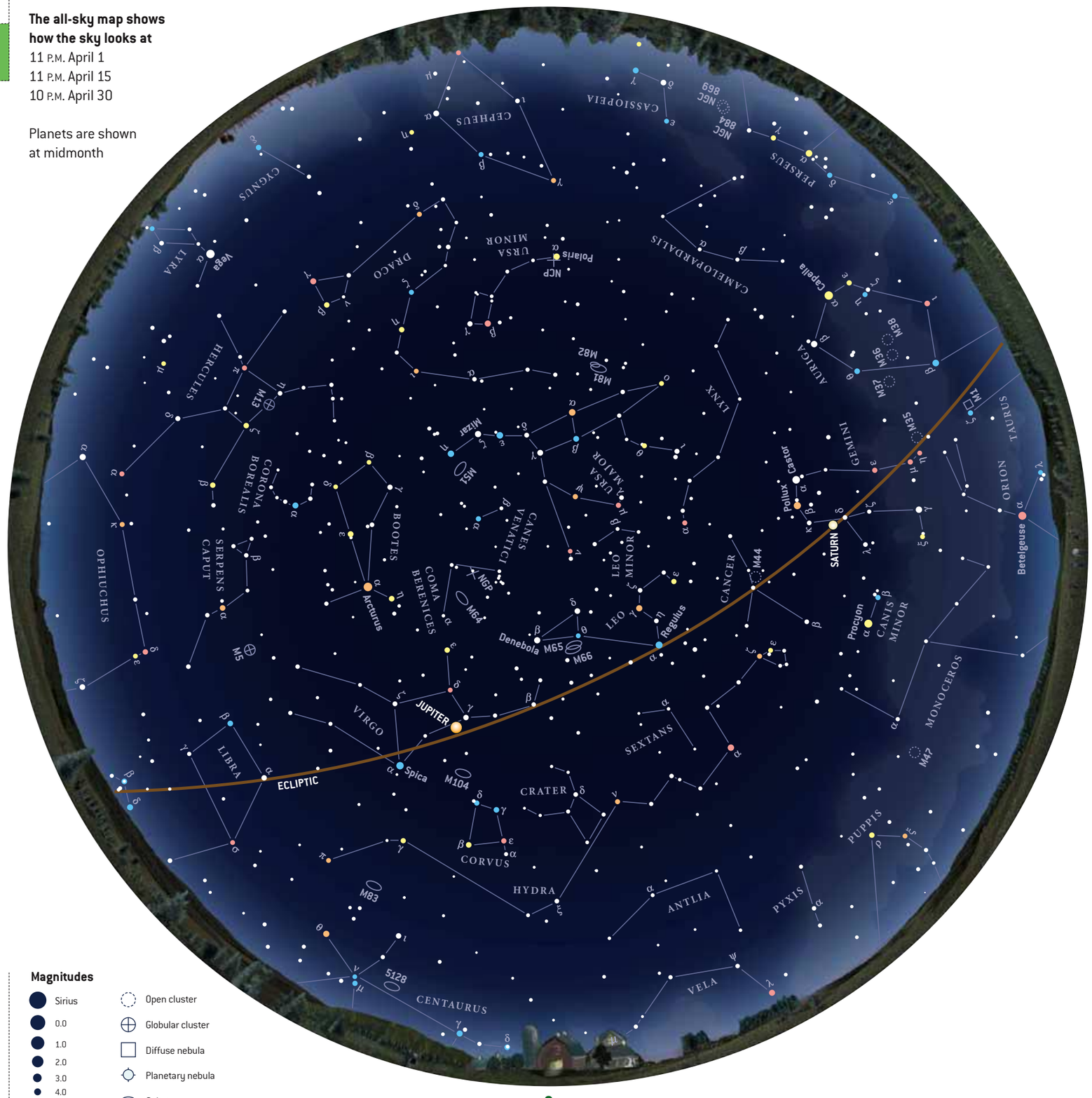
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
11 P.M. April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth



Magnitudes

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

april 05

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					[01]	[02]
[03]	[04]	[05]	[06]	[07]	[08]	[09]
[10]	[11]	[12]	[13]	[14]	[15]	[16]
[17]	[18]	[19]	[20]	[21]	[22]	[23]
[24]	[25]	[26]	[27]	[28]	[29]	[30]

01 Last Quarter Moon is at 7:50 P.M. EST

03 Jupiter is at opposition, noon EDT

The Moon passes 4° south of Mars, 6 P.M. EDT

04 The Moon passes 5° south of Neptune, 5 A.M. EDT

The Moon is at perigee (228,970 miles from Earth), 7:11 A.M. EDT

05 The Moon passes 3° south of Uranus, 6 P.M. EDT

07 The Moon passes 3° south of Mercury, 10 A.M. EDT

08 New Moon is at 4:32 P.M. EDT; annular/total solar eclipse

12 Mars passes 1.2° south of Neptune, 8 P.M. EDT

14 Jupiter is at aphelion (507.2 million miles from the Sun), 6 P.M. EDT

15 The Moon passes 5° north of Saturn, 9 P.M. EDT

16 First Quarter Moon is at 10:37 A.M. EDT

The Moon is at apogee (251,223 miles from Earth), 2:41 P.M. EDT

22 Lyrid meteor shower peaks

The Moon passes 0.6° south of Jupiter, 2 P.M. EDT

24 Full Moon is at 6:06 A.M. EDT; penumbral lunar eclipse

26 Mercury is at greatest western elongation (27°), 1 P.M. EDT

The Moon passes 0.7° north of Antares, 7 P.M. EDT

29 The Moon is at perigee (229,304 miles from Earth), 6:13 A.M. EDT

For definitions of terms, visit www.astronomy.com/glossary

THE DEEP SKY

The first few times you take a dip in the vast expanse of the Virgo cluster of galaxies, play it safe and stay close to shore.

Galaxies galore

Any of the Deep Field images beamed back by the Hubble Space Telescope shows the fathomless depths of the universe. Only 80 years ago, Edwin Hubble himself was striving to convince other astronomers all those fuzzy elliptical and spiral clouds in Virgo were actually galaxies like the Milky Way, not small solar systems in development. His efforts helped transform the universe from a mind-blowing size of some 100,000 light-years to a stupefying vastness billions of light-years across.

Novice observers are justifiably a little scared of diving into what Hubble called "the realm of the galaxies." Without the proper techniques and approach, panic can set in. To remain calm, first learn how your telescope shows the sky. How much sky will you see at low power? At 60x, depending on the eyepiece design, you'll be looking at a field diameter of close to 1°, or approximately twice the apparent size of the Full Moon. Lower power makes it easier to get around. Next, you need to match what you see to the stars shown on the chart at right.

Now, which way is up? Newtonian and Dobsonian reflectors simply invert the image, so just turn the chart upside down. Schmidt-Cassegrain telescopes and refractors with a star diagonal flip the image left to right but keep north up. So you need to copy the chart onto a transparency and flip it over.

SPIRAL GALAXY M88 is a showpiece of the Virgo cluster and should be a prime target for beginning observers. KIM ZUSSMAN

The last bit of confusion to conquer occurs when you point your scope at an object that does not lie due south. In this case, north and south on the sky do not lie straight up and down, but appear at an angle. Slowly turn the chart in your hands until its north points back to Polaris (for SCTs and refractors with a star diagonal), or until the chart's south points to Polaris (for Newtonian and Dob owners). Now, your chart is oriented the same way as the eyepiece field. Practice this skill, and you won't get lost again.

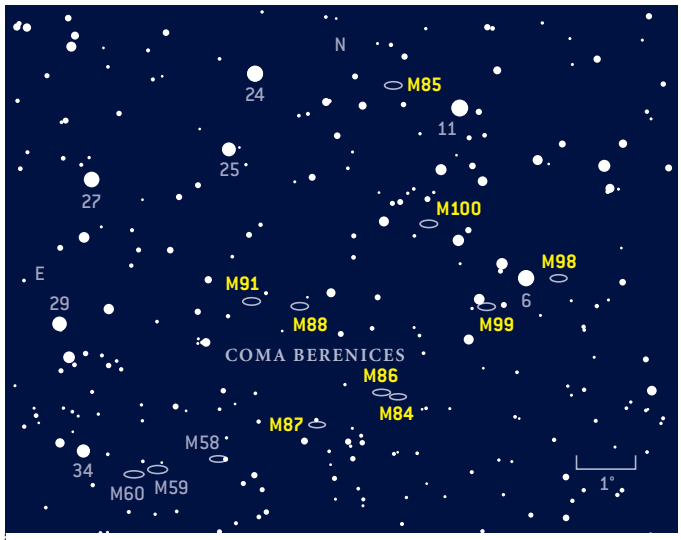
For your first foray into the galaxy realm, anchor yourself to the star 6 Comae Berenices. Then, shift one Moon-width west to hit M98, and slide back. Using the star pattern on the chart, step along the stars to the east and a bit north to the circular glow of the spiral galaxy M100. Next, plunge north past a field star to reach 11 Comae, which lies some 2°, or 4 Moon-widths, away.

If you have a drive on your telescope, turn it off for 5 minutes and relax while the sky slowly swings M85 into view. Backtrack to 11 Comae, south to M100, and west to 6 Comae.

Now you're ready for the deep end of the Virgo cluster. Draw the field size of your telescope/eyepiece combination on the chart. Begin again at 6 Comae, but this time, head southeast (down in the early evening sky) 1.5 Moon-widths to find M99. With firm resolve, keep going in the same direction another 4 Moon-widths to land on M84 and M86, both roundish, fuzzy clouds. This pair marks the primary signpost of the Virgo cluster.

If you get lost, don't get frustrated — simply reset your scope on 6 Comae and head back to M84 and M86. The biggest mental shift you face is that from here, you need to galaxy-hop instead of star-hop. Swim south and east to M87, and back again. Then, head northeast to locate M88 and M91 before returning to the M84/M86 pair.

With short out-and-back forays like this, you can remain calm enough to enjoy the experience. The first few times you're in this area, tour only at low power to solidify your telescope skills. Then, go back for a longer look at higher power.



THE REALM OF GALAXIES in Virgo can be intimidating, but if you take it slowly, you can find your way around. *ASTRONOMY*: ROEN KELLY

Martin Ratcliffe *is former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*

THE PLANETS

Saturn remains a standout evening object, but Jupiter comes to dominate the scene after night falls. Before dawn, Mars offers a series of nice conjunctions.

YOU CAN EASILY LOCATE JUPITER as it climbs higher in the east after the sky grows dark. *ASTRONOMY:* ROEN KELLY

Two brilliant planets appear soon after sunset and provide a visual feast for every observer. Saturn stands high overhead as soon as darkness falls — it's one of the first "stars" to come out. The second bright planet on view is Jupiter. Look for it in the direction opposite to where the Sun has set. Mars belongs to the morning sky, where it has a brief encounter with Neptune at midmonth.

Saturn, which starts high in the sky during twilight and sets after midnight, remains visible all evening among the stars of Gemini the Twins. A short distance above the planet lie the two brightest stars in Gemini, Castor and Pollux. At magnitude 0.1, Saturn shines noticeably brighter than this prominent pair. On April 15, a First Quarter Moon joins the trio, with the ringed planet lying 5° below the Moon. Saturn is now 3 months past opposition, so its shadow appears clearly on the rings east of the planet's disk.

January saw high drama when the Huygens probe made the first-ever descent through the atmosphere of Saturn's brightest moon, Titan (see Richard Talcott's story on page 36). Many of your friends might be surprised to learn that you can spot this 8th-magnitude moon easily through a small telescope. This month, you'll find Titan due west of Saturn April 8 and 24 and due east April 16. Titan passes due north of the planet April 4 (when a fainter moon, Iapetus, lies close by) and April 20. Titan appears due south of Saturn April 12 and 28.

Iapetus travels around Saturn in a larger orbit than Titan, and consequently, Iapetus moves more slowly. In early April, Titan and Iapetus lie in close proximity, but Titan pulls ahead quickly. Iapetus shines at 11th magnitude during the first few days of April and brightens slowly as it approaches western elongation April 24. By this date, Iapetus glows at its brightest, magnitude 10.1, comparable to Tethys, which orbits much closer to the planet. Iapetus then lies farthest from Saturn of any visible moon. Titan lies nearly 3' west of Saturn, while Iapetus is a full 8' west.

Shining at magnitude –2.5, **Jupiter** maintains its brilliance throughout April. Its location opposite the Sun in our sky underlines the planet's opposition that occurs April 3. When any outer planet achieves this special position, it remains visible all night. Opposition also brings the planet closest to Earth, so it shines brightest and appears largest, making this the best time for viewing. Furthermore, opposition places a planet due south at local midnight, the position where we view it through the least amount of Earth's atmosphere.

At this year's opposition, Jupiter's apparent size in a telescope reaches 44" — the largest of any outer planet. (Venus can get larger, but only in twilight and as a thin crescent.) This large apparent size offers great opportunities for viewing cloud features in the jovian atmosphere. Jupiter completes one rotation in less than 10 hours, allowing the entire planet to be viewed during a single night this month.

Make the most of Jupiter's appearance this year because next year, it will lie in Libra and never climb much higher than 35° above the horizon for observers at mid-northern latitudes. This year, it lies in Virgo and stands nearly 50° above the southern horizon around midnight. Higher altitude also reduces the effects of atmospheric turbulence.

On April 3, Jupiter lies 10° northwest of Virgo's brightest

JUPITER DOMINATES THE NIGHT throughout April, when it comes to opposition and best visibility. NASA/JPL/SSI

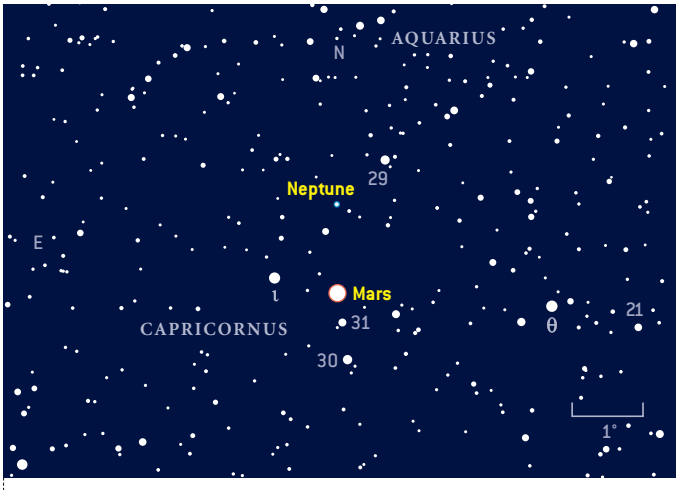
star, 1st-magnitude Spica. Throughout April, the planet's westward motion carries it toward Porrima, Virgo's second-brightest star, so that by the 30th, Jupiter lies 1.3° south of it. On April 22, you'll find Jupiter 6° to the upper right of the almost Full Moon.

Jupiter's four bright moons, Io, Europa, Ganymede, and Callisto, continue to perform their elegant dance around the planet. Io takes less than 2 days to orbit, so you can see its relative position change in an hour or so — less when it appears close to Jupiter. Our line of sight lies in the plane of the moons' orbits, so we see occultations, eclipses, and transits of the moons at various times.

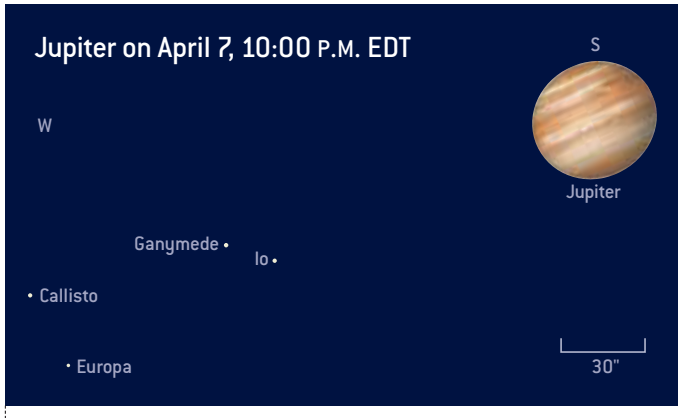
Moving from the night's brightest planet to the faintest, **Pluto** lies near a 3.5-magnitude star in Serpens Cauda, a constellation that appears above Sagittarius in the southeastern morning sky. Early April finds Pluto 24' north-northeast of Xi (ξ) Serpentis. Having a bright star near the planet's location drastically cuts the time required to find the right field of view. By the end of April, Pluto's apparent distance from Xi has grown 50 percent, with the planet moving to the northwest of the star from night to night. If you own an 8-inch or larger telescope, you should be able to reach stars as faint as 14th magnitude. In that case, Pluto's motion relative to the background stars will betray its identity.

Although Pluto rises before midnight, don't think of searching for it until after midnight, when the area reaches a decent altitude. The region lies due south at approximately 5 A.M. local daylight time.

Mars rises around 3 A.M. April 1 and an hour earlier by month's end. During this period, it crosses from northern Capricornus into Aquarius. You can follow its eastward progress all month. On April 8, Mars lies 0.7° south of Theta (θ) Capricorni; on the 14th, 0.2° east of Iota (ι) Cap; on the 20th, 1.2° north of Gamma (γ) Cap; and on the 22nd, 1.1° north of Delta (δ) Cap. Finally, the planet passes just one Moon-width (0.5°) north of the 4.3-magnitude bluish star Iota Aquarii April 29. Shining at 1st magnitude, Mars appears conspicuously brighter than any of these stars.



MARS PASSES NEPTUNE during the early morning hours of April 13, providing a good opportunity to spy the distant gas giant. *ASTRONOMY:* ROEN KELLY



THE FOUR BRIGHT MOONS of Jupiter line up on the western side of the planet the evening of April 7. *ASTRONOMY:* ROEN KELLY

As our planet's orbital motion brings us slowly closer to Mars, the Red Planet grows slightly in apparent diameter. It reaches almost 7" across by the end of April. Experienced digital imagers should be able to pull out some detail on the martian surface now, but most of us will have to wait until midsummer before the planet becomes a decent target for our telescopes. Mars will reach a favorable opposition in early November.

On April 12/13, Mars passes 1.2° south of **Neptune**. Although Neptune is intrinsically a much larger planet, its greater distance makes it appear small and faint. Neptune currently lies some 20 times farther from Earth than does Mars. At this conjunction, Mars shines at magnitude 0.8, while Neptune glows at magnitude 7.9, nearly 1,000 times fainter. You'll need binoculars to spot Neptune. Neptune's disk measures 2.2" across and requires a small telescope and good atmospheric seeing conditions to see it clearly.

Uranus reappears in the morning sky at the end of April. On the 30th, it lies 1.7° southwest of 4th-magnitude Lambda (λ) Aquarii. Mars is the most prominent nearby object, located 10° to the upper right of Uranus. You'll want to use binoculars to spot Uranus, which glows at magnitude 5.9. Look for it several degrees above the east-southeastern horizon at least 75 minutes before local sunrise.

Innermost **Mercury** has its poorest morning apparition of the year for Northern Hemisphere viewers this month — it never climbs more than a few degrees above the eastern horizon before twilight makes it impossible to see. Mercury reaches greatest western elongation April 26, when it shines at magnitude 0.4 and stands 4° high in the east 30 minutes before sunrise. The next favorable appearance of Mercury will be in the evening sky in early July.

METEORS AND MOONS

Earth's Moon takes center stage this month, blocking the Sun from view for a brief time April 8 and passing into Earth's outer shadow April 24.

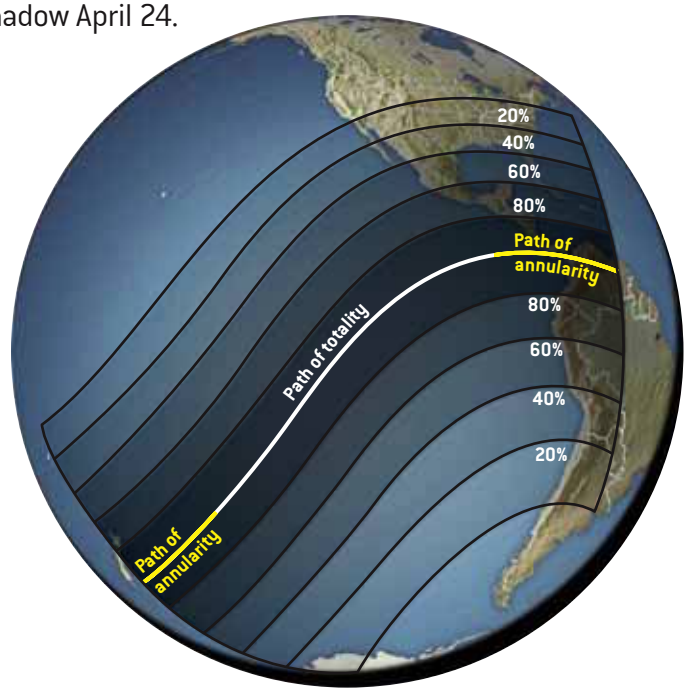
An American eclipse

The rarest type of solar eclipse returns to Earth this month after 18 years. Just 5 percent of all solar eclipses are hybrid: total over part of the path, and annular over the rest. On the section of the eclipse track near local noon, that part of Earth lies close enough to the Moon for the eclipse to appear total. But at the ends of the track, around sunrise and sunset, those parts of Earth lie far enough from the Moon that our satellite can't cover the whole Sun. Observers there see an annular eclipse, a thin ring of Sun left around the Moon.

On April 8, the central part of the Moon's shadow traces a narrow path from east of New Zealand to northern South America. Maximum totality comes in the middle of the Pacific Ocean and lasts 42 seconds. The longest annular eclipse occurs in Venezuela and endures 34 seconds.

A partial eclipse can be seen across southern North America and western South America. Use the map at right to find out how much of the Sun the Moon will block. As always, any time you observe the Sun when it is not totally eclipsed, use proper eye protection.

The month's second eclipse occurs the morning of April 24. This is a penumbral lunar eclipse, which means the Moon passes through the outer, lighter part of Earth's shadow. Observers with sharp eyes in most of North and South America should see the northern half of the Moon take on a slightly darker hue as our satellite sets that morning.



THE SOLAR ECLIPSE OF APRIL 8 will be visible across a wide swath of the Americas and the Pacific Ocean. *ASTRONOMY*: ROEN KELLY

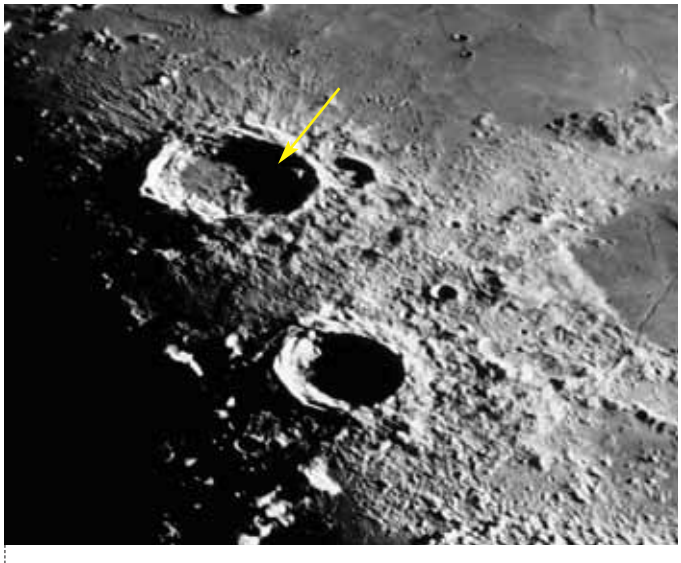
Harping on meteors

April's claim to meteor fame is the annual Lyrid shower. This stalwart peaks this year the night of April 21/22. Unfortunately, Full Moon arrives just 2 days later, and its brilliance in the night sky will significantly reduce the number of visible meteors. Your best bet is to observe before dawn the morning of April 22, when you might see up to 10 meteors per hour. Lyrid meteors appear to radiate from the constellation Lyra the Lyre, which climbs highest in the predawn hours.

On a frigid shore

A week after New Moon, the Sun rises over the lunar crater Aristoteles. This 54-mile-wide crater lies on the southern shore of Mare Frigoris, in the Moon's northeastern quadrant. It forms a beautiful pair with Eudoxus to its south, near the long chain of the Caucasus Mountains. As sunlight illuminates the crater's inner walls, elaborate terracing becomes noticeable. Hills dot the crater's floor, and the highest peak lies off-center, near the southern wall.

The northwestern wall appears particularly bright as the first rays of sunlight strike it, and it shows evidence of slumping — the floor at the wall's base is very hilly. The crater's rim rises 2 miles above the floor. Tiny craterlets pit the outer walls, and a small crater, Mitchell, makes an impression just east of Aristoteles. Enjoy the rapidly changing appearance of this magnificent crater in the days surrounding First Quarter phase.



THE CRATER ARISTOTELES (arrow) forms a nice pair with Eudoxus to its south (below in this image). Catch sunrise over the region just before First Quarter Moon. FROM *CONSOLIDATED LUNAR ATLAS* (LPL/UA)

COMETS AND ASTEROIDS

A binocular comet steps across the Dragon's tail into Great Bear country, while a bright asteroid serves as a useful guide to the western sector of the Virgo galaxy cluster.

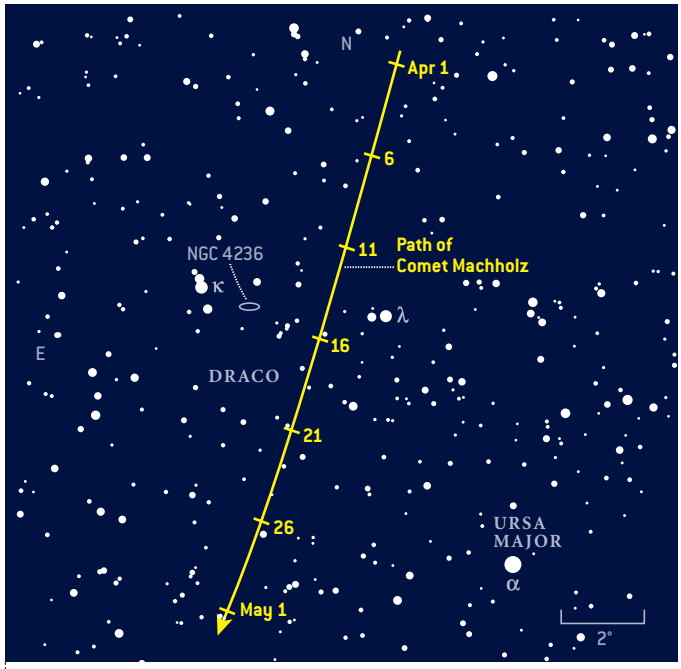
All night long

Occasionally, a comet rewards us by staying visible throughout the night. In March 1996, the great comet Hyakutake passed near Polaris and remained on view all night. This month, Comet C/2004 Q2 (Machholz) fits the bill. It currently resides in the far northern sky and does not set unless you live south of the United States or Europe.

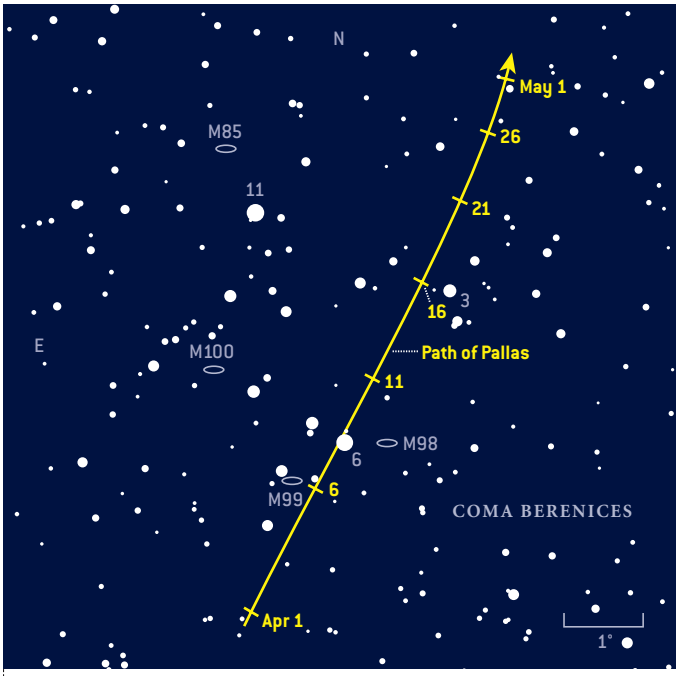
Shining nicely at about 7th magnitude, this dirty snowball is easiest to find under a dark sky. Try sweeping with binoculars about halfway between Polaris and the bowl of the Big Dipper. From a city backyard, you'll probably need a bit more aperture. Use the stars Lambda (λ) and Kappa (κ) Draconis to start your star-hop.

A short dust tail should be pointing away from Polaris. Its apparent length depends on how dark your sky is. Observers in rural areas always see a longer tail than those who live near major sources of light pollution.

With a couple of notable exceptions, namely Andromeda's M31 and Triangulum's M33, Comet Machholz glows brighter than any galaxy in the Messier catalog. This means an 8-inch scope from the suburbs will reveal some inner detail. After a survey of the comet's head and tail at low power, bump the magnification up to 120x or so.



COMET MACHHOLZ remains near the North Celestial Pole in April, providing nice views through binoculars all night long. *ASTRONOMY:* ROEN KELLY



THE ASTEROID PALLAS serves as a good guide this month to some of the brighter galaxies in the Virgo cluster. *ASTRONOMY:* ROEN KELLY

Star charts of this area typically plot the large, eye-catching galaxy NGC 4236 and will list an appealing total brightness of magnitude 9.6. But beware: The galaxy's light spreads out over such a large area that this object proves a considerable challenge in small scopes. The barred spiral has been glimpsed in 4-inch scopes under extremely dark skies.

Perfect Pallas

Asteroid 2 Pallas appears bright because it is large (325 miles across) and comes relatively close to Earth. Heinrich Olbers discovered Pallas in March 1802, making it the second asteroid to be found. This month, Pallas travels in front of the "realm of the galaxies," making it a roving guide through what many beginners consider a scary part of the sky.

A primary key for unlocking secrets of the Virgo cluster is the star 6 Comae Berenices. If you get lost, don't worry. Just go back to the tail of Leo, hop along the base to 6 Comae, and start again. Between April 7 and 9, Pallas lies less than a Moon-width away from this 5th-magnitude star.

After 6 Comae and four or five 6th- to 7th-magnitude stars, Pallas is the next brightest object in this area. From one night to the next, it should be easy to track this main-belt asteroid as it moves slowly across the sky.

Seeking the first galaxies

The Hubble Telescope's million-second stare into space is our deepest look at the universe, but astronomers disagree over what it shows. /// BY FRANK SIETZEN, JR.

Astronomers have completed their first analyses of the sources and structures contained within the Hubble Ultra Deep Field (HUDF). Their preliminary report, made at the Space Telescope Science Institute (STScI) in Baltimore last September, suggests the HUDF contains some of the earliest galaxies known.

In terms of cosmic age, these galaxies are 95 percent as old as the universe itself, forming less than 1 billion years after the Big Bang. But while a consensus emerged among the analysis teams about the age of these galaxies, debate arose as to whether their stars were hot enough to transform the universe from opaque darkness to one filled with light.

The HUDF was generated by the telescope's optical Advanced Camera for Surveys (ACS) and deep, penetrating views by the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). Analysis of the HUDF image showed the youngest galaxies emerging as more than 100 indistinct red blurs across the entire width of the picture — a clutter of infant dwarf galaxies. This suggested to astronomers that the emergence and maturity of galaxies followed a pattern that led to today's massive structures. "What we see here is a complex array of objects — some 10,000 galaxies are visible," says Steve Beckwith, the institute's director. "They are faint, fuzzy things at the edge of the universe," he adds. "These things are just train wrecks."

Astronomers have long sought to affirm the universe contained a reionization epoch, a period when hydrogen atoms absorbed enough energy from ultraviolet light that they were stripped of their electrons. The effect was to make the universe transparent to visible light.

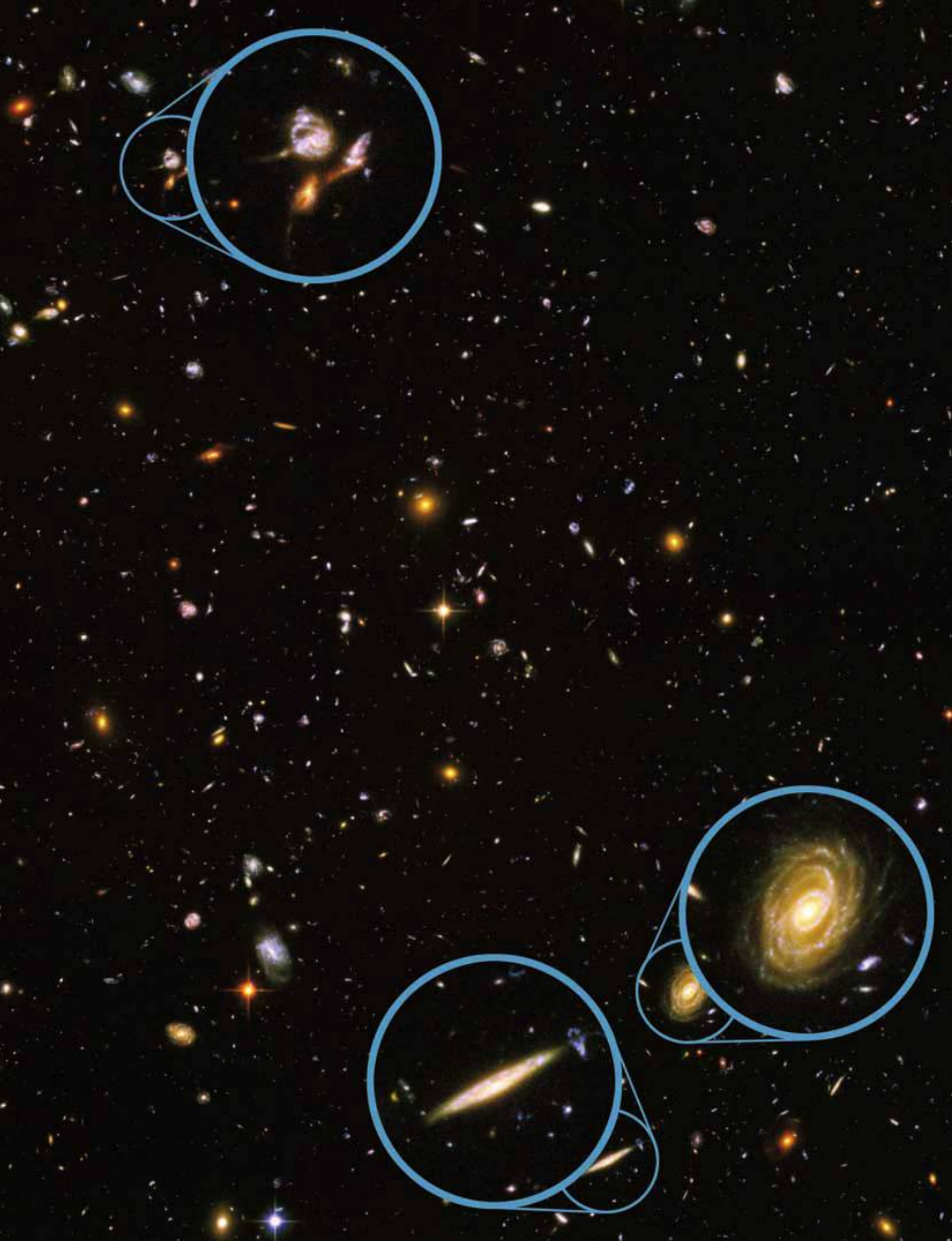
This followed an earlier era — the Dark Ages — when the ultra-hot universe was an ionized haze of hydrogen nuclei and free-moving electrons. As the universe cooled, hydrogen nuclei captured the electrons, creating a cosmic haze that absorbed all light. When the first stars ignited, their ultraviolet radiation returned the hydrogen haze to its ionized state, allowing visible light to beam across the universe.

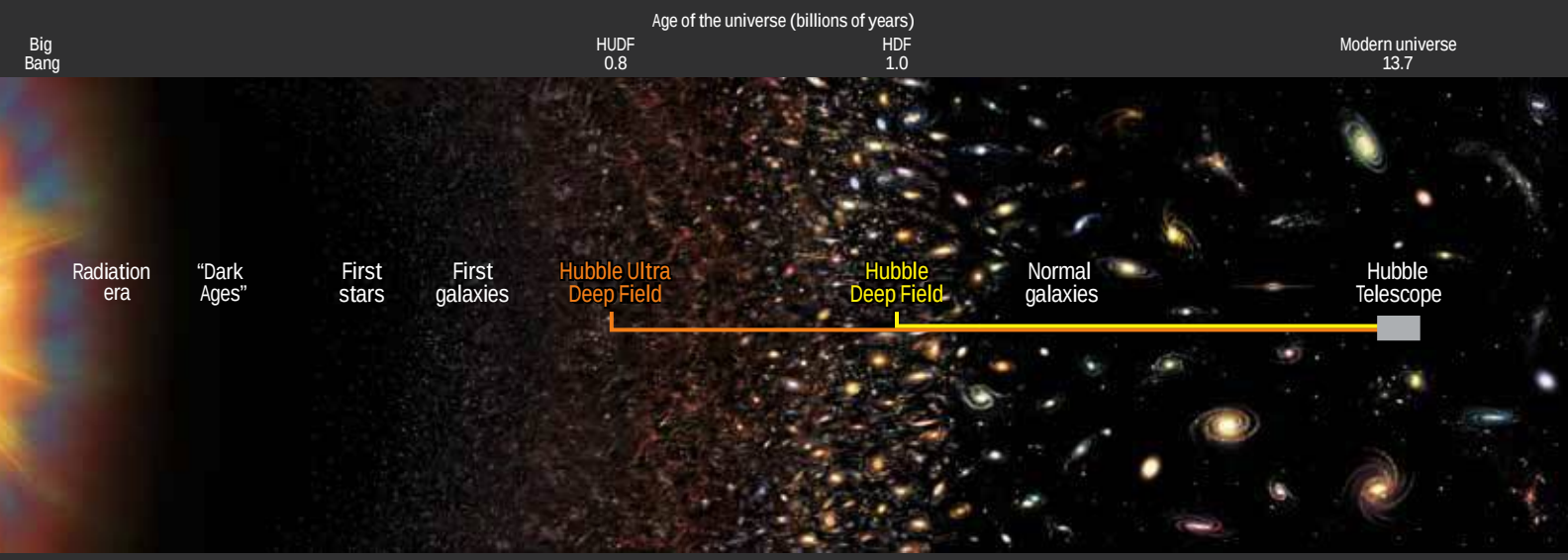
Reionization is thought to have ended between 500 million to 1 billion years after the Big Bang. Galaxies so distant have been nearly impossible to locate, and some astronomers believe they see such structures within the HUDF.

But not all agree. At the September 2004 briefing, where five teams of astronomers reported their analyses, interpretation of what they were seeing differed. "Like most cutting-edge science, there is controversy about the results," Beckwith says. Some believe the HUDF has found objects that completed cosmic reionization by a redshift of 6 (or z = 6, in astronomical parlance).

"This is the use of the telescope to probe through time, through the cosmic fog," says Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics. It was a search "for the cosmic dawn," he suggests. Of the hydrogen in the early universe, Kirshner asks, "It cools and recombines, but what then?"

HUBBLE ASTRONOMERS COMBINED 800 ACS FRAMES — total exposure time: 1 million seconds, or 11.3 days — to create the HUDF. The space telescope captured some 10,000 galaxies, seeing some as they were when the universe was less than 850 million years old. In some wavelengths, the HUDF is 4 times more sensitive than the original Hubble Deep Field, a 5.9-day-long exposure released in 1996. NASA/ESA/S. BECKWITH AND THE HUDF TEAM, STScI





PROBING THE HUBBLE ULTRA DEEP FIELD takes us from dwarf stars within our own Milky Way Galaxy to the most distant galaxy astronomers have confirmed through direct measurements. This glimpse of the early universe is the best available until Hubble is upgraded or its successor flies. *ASTRONOMY:* ROEN KELLY

The team led by Andrew Bunker, University of Exeter, United Kingdom, addressed star-forming galaxies at redshifts near 6. "These distant galaxies are very red," he explains. Using the W. M. Keck telescopes in Hawaii, Bunker's team identified 50 high-redshift galaxies in the HUDF. "We were the first to prove these ACS-selected galaxies really are distant: 90 percent of the way back to the Big Bang," he says. Bunker explains that the level of star formation recorded in the HUDF at redshift 6 is only one-third that required for reionization. "Are there undiscovered, fainter sources forming globular clusters?" he asks. "Is there star formation at even earlier times?"

Massimo Stiavelli, S. Michael Fall, and Nino Panagia (STScI) argue chemistry resolves this problem. These distant objects could put out enough energy to reionize the universe if their stars held a relatively small complement of "metals," elements heavier than helium. "Early in the life of the universe, when only few generations of stars had been formed, the metallicity of the stars was very low," Stiavelli says.

Haojing Yan of the Spitzer Science Center at the California Institute of Technology and Rodger Windhorst of Arizona State University found the number of dwarf galaxies rapidly increases at fainter magnitudes within the HUDF. They compared these "mom-and-pop"-size structures to the few "large corporations" at this epoch. They conclude the steep increase of this faint dwarf population did generate enough ultraviolet light to complete reionization of the universe by redshift 6 — even if the dwarf galaxies contained an amount of heavy elements similar to that found in today's galaxies.

The team of Sangeeta Malhotra and James Rhoads (STScI) found the number of galaxies near redshift 5.9 was 4 times greater than that in the remainder of the HUDF. The team used Hubble spectroscopic data to measure the galaxies' distances. "The most distant galaxy that has been confirmed spectroscopically is at redshift 6.7," Malhotra says. "We have confirmed redshifts between 4 and 7 for about 50 galaxies, and about 110 galaxies with redshifts around 1." The team has also identified the nearest objects in the HUDF — dwarf stars in our own galaxy.

"The HUDF illustrates the unique role of deep Hubble data, and the merits of publicly available data sets," says Lick Observatory's Richard Ellis. Astronomers agree Hubble's cameras have captured an abundance of early, young galaxies, galaxies formed when the universe was only 600–900 million years old. "This is an observational first," Ellis says. "Has Hubble found the first sources switching on after the Dark Ages, during which there was only pure hydrogen and helium?" he asks. And are these sources sufficient to be responsible for ending the Dark Ages?

The answer will come only by attempting to detect even earlier galaxies. The newly completed WideField Camera 3, if installed on Hubble, will be key to imaging these earlier structures — if they can be detected at all. But although Hubble was only able to glimpse the cosmic dawn, its successor, the James Webb Space Telescope, will scrutinize the early universe in detail when it flies in 2011. A

/// DEEP FIELDS COMPARED

	Hubble Deep Field*	Hubble Ultra Deep Field**
Name:		
Released:	January 15, 1996	March 9, 2004
Constellation:	Ursa Major	Fornax
Target:	12h36m49.5s 62°12'58.0"	3h2m40.0s –27°48'0.0"
Instrument:	WFPC2	ACS
Images taken:	12/18/1995 to 12/28/1995	9/24/2003 to 1/16/2004
Exposures:	296	800
Total exposure:	507,000 seconds (5.9 days)	1 million seconds (11.3 days)
Orbits:	150	400
Time to similarly image the whole sky:	900,000 years	1 million years

* Renamed Hubble Deep Field North after the telescope imaged a similar patch in the southern constellation Tucana in October 1998.

** NICMOS survey information is not included.

Frank Sietzen, Jr., *covers NASA and the space program for United Press International in Washington. He is a coauthor of* New Moon Rising: The Making of the New Space Vision and the Remaking of NASA *(Apogee Books, 2004).*

Find more on the HUDF and Hubble's future at www.astronomy.com/toc

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ASK ASTRO

Gravity's speed, gravity's lens, Mars mikes

GRAVITY'S SPEED

Why do physicists think gravity travels at the speed of light? — ANTONIO MALLARINO, AMES, IOWA

No experiment has yet measured the speed of gravity, but that hasn't prevented theorists from coming up with some answers. According to Newton, gravity acts instantly — that is, "action at a distance" — and so, from that viewpoint, gravity travels at an infinite speed.

However, Einstein's special relativity introduced the idea of a speed limit for the movement of all fields or information — the speed of light. Einstein constructed his general theory of relativity on the foundation of his earlier and more restricted special relativity, so light-speed remains the universe's ultimate speed limit.

And indeed, when physicists solve Einstein's equations, wherever small deviations appear in space-time (the fabric of space in relativity), the gravitational field at a given place and time does not change instantly, but appears "retarded." That is, changes in the gravity field depend on the source's earlier behavior — a time delay given by distance from the source divided by the speed of light. These solutions also reveal wavelike ripples that move through space-time precisely at the speed of light. These are gravitational waves.

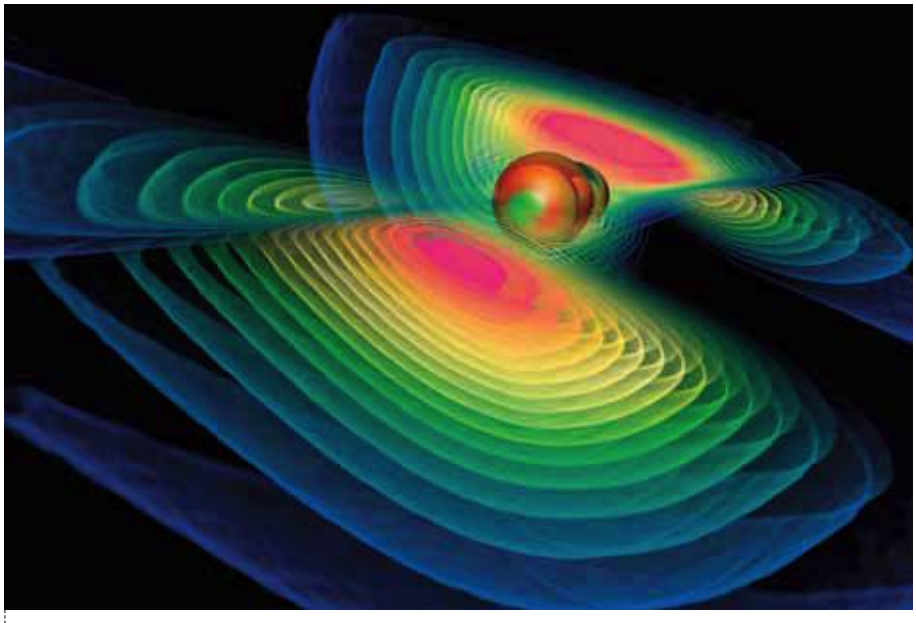
So, general relativity predicts gravitational interaction and gravitational waves move with the same speed as light. On the other hand, alternative theories of gravity predict, via one mechanism or other, that the speeds *could* be different. This is why measuring the speed of gravity is an important test of Einstein's theory.

So far, there is no experimental evidence one way or the other on the speed of gravity. In 2002, one team of experimenters measured the effect of Jupiter's gravity field on light from a distant quasar as the planet moved in its orbit across the field of view. The group argued that, because of Jupiter's motion, the deflection experienced by the light rays would be sensitive to the speed at which Jupiter's gravity field propagated through space. They claimed to have shown the speed of gravity was within about 20 percent that of light.

But other scientists showed decisively that, to the experiment's level of precision, the effect being measured did not depend on gravity's speed, but instead depended only on the speed of light. The consensus of scientific opinion is that while the experiment was interesting, it provided no information about how fast gravity moves.

Such a measurement likely will have to wait until we've detected gravitational waves directly. A worldwide array of gravitational-wave observatories using laser interferometry now is operational, and there is a reasonable chance, once suitable upgrades are in place, that the array will detect gravity waves successfully before the decade ends.

When this happens, extremely precise measurements may be possible. These advanced detectors will be able to "see" cataclysmic events, such as a supernova or the merger of two neutron stars, at a distance as great as 500 million light-years. By comparing arrival times of the bursts of electromagnetic and gravitational waves with a precision of a few seconds, we could check for any difference in speed to the level of a few parts in 10^{17}. This would be a stunning check of a key prediction of general relativity. — CLIFFORD WILL, WASHINGTON UNIVERSITY, ST. LOUIS



GRAVITY WAVES RADIATE THROUGH SPACE as two black holes merge in this computer visualization of the process. Although gravitational waves have not yet been seen, relativity theory suggests they exist, and facilities around the world are looking for them. Catching a passing gravity wave means detecting the displacement of a laser beam by one-hundred-millionth the diameter of a hydrogen atom. WERNER BENGER, ZUSE-INSTITUT BERLIN AND MAX-PLANCK-INSTITUT FÜR GRAVITATIONSPHYSIK

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P.O. Box 1612, Waukesha, WI 53187.
Please tell us your full name and where you live.

GRAVITY'S LENS

When a gravitational lens magnifies a background galaxy, why don't we see the object doing the lensing, as we would if looking through an optical lens? — ROBERT HERTRICK, PITTSBURGH

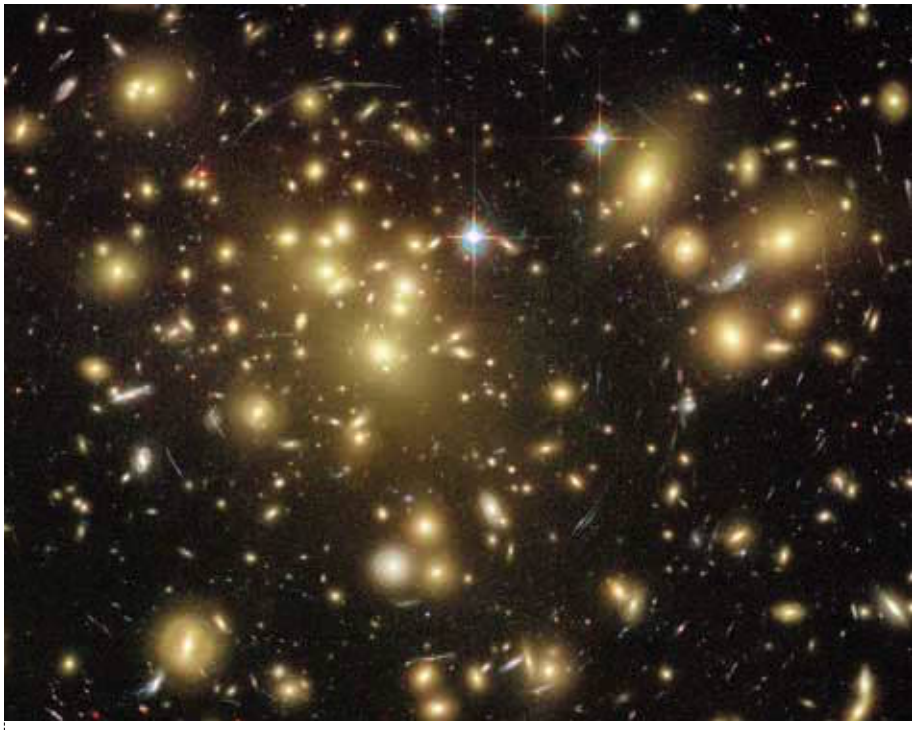
Gravitational lensing is one of the more beautiful and unusual phenomena physicists have predicted and astronomers have stumbled across. When the gravity of a foreground galaxy distorts and magnifies light from a background galaxy, the result is either a single Einstein ring or multiple images of the object.

In all cases, these images surround the object responsible for the lensing. So, if we think of the lensing galaxy as a sort of magnifying glass, why doesn't the image appear superimposed? It's as if we're looking through a magnifying glass but seeing an image 3 feet to its side.

In fact, the image does appear inside the lens — it's just that the lens is invisible. Light does not have to pass through a galaxy to be deflected by its gravity. Take, for example, the beautiful image of the galaxy cluster Abell 1689 captured by the Hubble Space Telescope. Gravity binds the cluster's bright, yellow galaxies, and the density of galaxies traces the depth of the cluster's gravity well, roughly telling us where the invisible gravitational field lies. (X-ray views, which reveal intensely heated gas within the cluster, provide another way to "see" the gravitational field.) Blue-white arcs among the yellow galaxies are lensed images of background objects seen within gravity's lens.

Not every example of lensing in the cosmos is gravitational, of course. Just as light rays bend when they interact with the electrons in a piece of glass, so astronomers can see — in X rays — objects lensed when their light interacts with electrons in the dust of a foreground galaxy. The resulting halos, analogous to Einstein rings produced by gravitational lensing, were first observed in 1983. Of course, if you can't see the dust itself, then such halos would be — at first — as mysterious as those made by gravity. Bruce Draine and Nick Bond of Princeton have suggested using the geometric relations in the lensing of these halos to determine cosmological distance scales, something astronomers have been doing with gravitational lenses for some time.

Texts on gravitational lensing say the images produced are not true images in an optical sense: Their light is not focused to a point at the observer. But our telescopes have no problem gathering up the light and taking care of the focusing themselves. **— SIMON DEDEO,** PRINCETON UNIVERSITY



THE SPACE-WARPING GALAXY CLUSTER Abell 1689, which lies 2.2 billion light-years away in the constellation Virgo, contains trillions of suns, but most of its matter can't be seen. Still, this unseen mass affects space, bending the light from individual galaxies behind the cluster into multiple curved, bluish arcs. This image is about 2 million light-years across. NASA/ESA AND THE ACS SCIENCE TEAM

MARS MIKES

Why hasn't NASA flown a microphone to Mars? Will future probes, to places like Europa, carry audio sensors? — JOHN FRANCIS, VICTORIA, BRITISH COLUMBIA

The microphone flown on the 1999 Mars Polar Lander (MPL) would have been the first on Mars had the spacecraft landed successfully. There is some skepticism about the scientific value of recording the sounds of Mars or another world, although everyone acknowledges the public-relations value. Resources and the competition to get other instruments aboard is fierce, and sensors viewed solely as "public relations" easily become sidelined.

Cameras were regarded similarly early in the space program; now, imaging plays an important science role. Microphones may follow a similar path. Once used on a mission, microphones may become integrated into the regular battery of science instruments. One example is an acoustic anemometer, a device that uses sound waves to measure wind speed.

The Huygens probe dropped into Titan's atmosphere in January carried an acoustic experiment to be used during the landing. Serious proposals to send microphones to Venus have been made already. Scientists interested in the sounds of other worlds are pursuing several future possibilities. **— GREGORY T. DELORY,** UNIVERSITY OF CALIFORNIA AT BERKELEY

Shoot sharper with film

After browsing images in *Astronomy*, you may think a CCD camera is needed for deep exposures of astronomical targets. CCD cameras have some advantages, but the cost remains high for quality. However, many astrophotographers still produce stunning images on film that rival CCD quality. CCD cameras have an advantage because they record light in a

JASON WARE has been a dedicated film astrophotographer for years. He's shown here — ready to begin a night of skyshooting — with his 6-inch Meade 152 ED refractor.

linear fashion. If you double the exposure, you obtain twice the data.

This allows an imager to capture faint celestial objects by summing exposures taken at different times — even on different nights. Some stunning CCD images published recently have more than 10 hours of exposure data captured in manageable 20- to 30-minute chunks.

Film behaves linearly during only a small portion of its exposure range. A look at the light-sensitivity curve of a particular film will show a low-contrast "toe" at the bottom left of the graph. It requires a certain amount of exposure time to overcome this. Thus, it's not worthwhile to sum together a series of short exposures like those taken through a CCD camera.

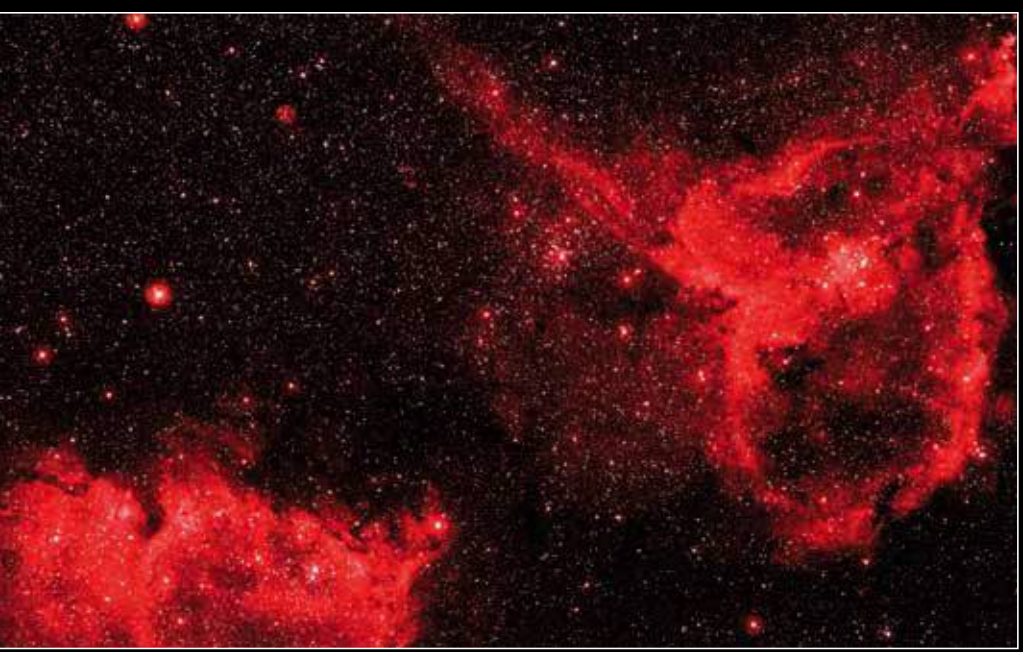
To overcome film's limitations for capturing faint objects, we must do one of two things: either use "fast" optical systems (those with low focal ratios) or shoot very long exposures.

Schmidt cameras and fast lenses are ideal for capturing deep, wide-field exposures of extended celestial objects (basically, any object that's not a star).

I use a 12-inch Meade f/2.2 Schmidt camera. If the price of this camera places it out of your reach, used 8-inch Celestron f/1.8 Schmidt cameras are available for sale occasionally. Fast photo lenses in the 200 millimeter to 300mm range with focal ratios of 2.8, while somewhat expensive, also can produce stunning photos.

You can make long exposures on film more easily with slower optical systems by using an autoguider. An autoguider is a small CCD camera that hooks up to a guide scope.

The camera interfaces with both a computer and your telescope's drive. If a "guide star" you've selected begins to drift off the pixels of the CCD camera, the autoguider will re-center the star. I've made several successful 2-hour exposures on high-resolution black-and-white film through an 8-inch Meade f/10 Schmidt-Cassegrain telescope using a Santa Barbara Instrument Group (SBIG) ST-4 autoguider.

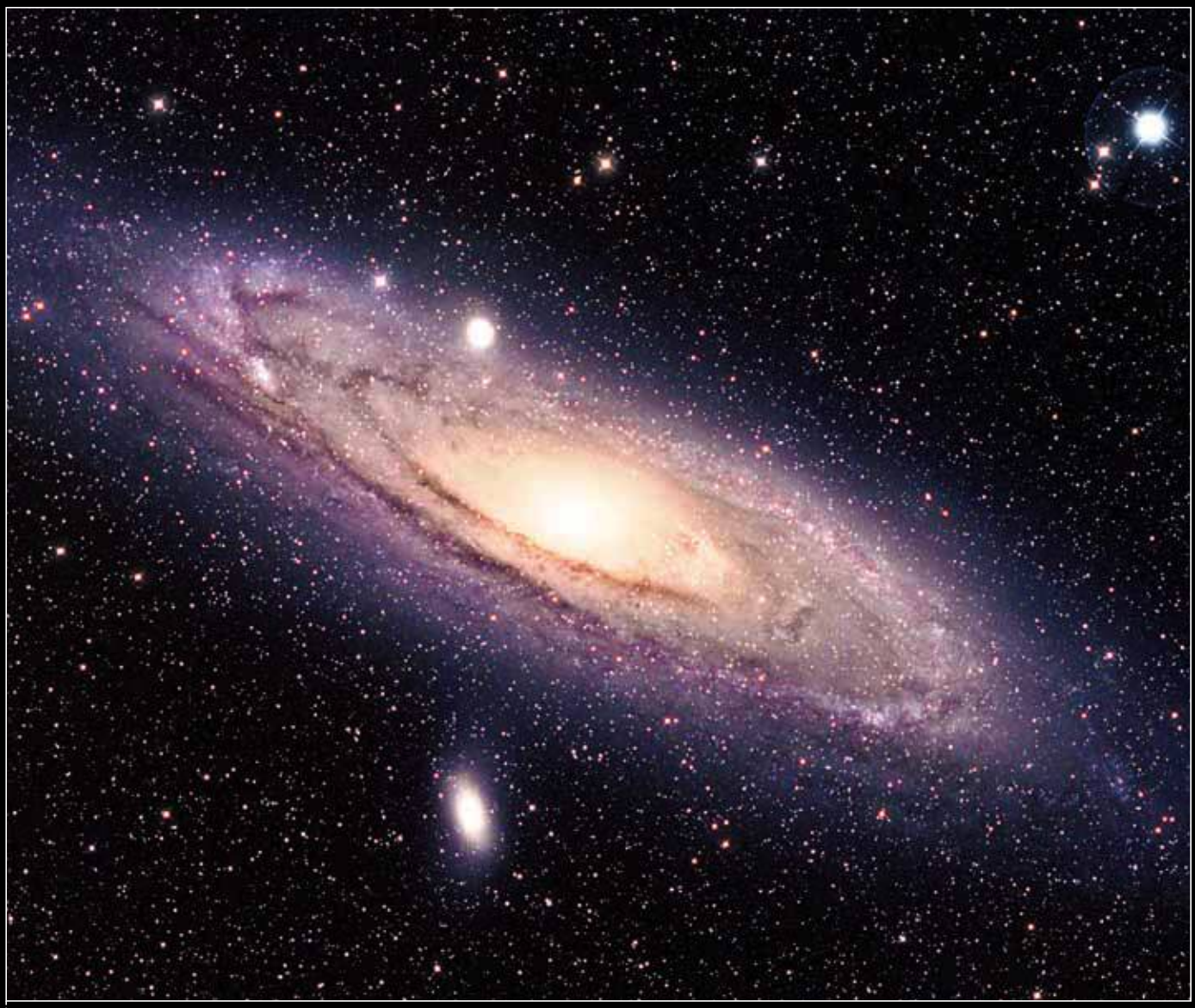


THE HEART AND SOUL NEBULAE (IC 1848 [lower left] and IC 1805) in Cassiopeia are examples of open clusters associated with emission nebulae. The author imaged these objects with his 12/16-inch Meade Schmidt camera at f/2.2. He took two 30-minute exposures on Kodak Technical Pan film through a #92 red filter and two 15-minute exposures on Fuji 100 color print film.

Image processing

The long-exposure images appearing in *Astronomy* and elsewhere have been heavily enhanced — you're not seeing the camera's raw data (film or CCD). Photographers use software such as Auriga Imaging's *Registar* and Adobe's *Photoshop* to combine multiple exposures and reveal detail never seen using conventional darkroom techniques.

THE RHO OPHIUCHI complex offers one of the sky's most colorful regions. To image this large area, the author used his 12/16-inch Meade Schmidt camera at f/2.2. He took two 10-minute exposures on Kodak Technical Pan film and two 15-minute exposures on Fuji 100 print film.



THE ANDROMEDA GALAXY (M31) may be the most famous of all deep-sky objects. Because it's larger than four Full Moons side-by-side, a wide field of view is needed to image it. The author used his 12/16-inch Meade Schmidt camera at f/2.2 and took five 10-minute exposures on Kodak Technical Pan film, two 5-minute exposures on Kodak Technical Pan film, and two 15-minute exposures on Fuji Superia 100. The author created pictures with different exposure times on the same type of film to record detail in both the core and outer regions of this galaxy.

Working with digital data from CCD cameras, astrophotographers developed many of the computerized enhancement techniques in use today. What you may not realize, however, is that a good scan of a properly exposed negative or slide can produce data similar to that obtained with a CCD. The key is to produce a high-quality scan.

You can buy a quality 35mm film scanner for a few hundred dollars. A high-end medium-format scanner, on the other hand, can cost as much as a CCD camera. Several astronomical imaging web sites, however, offer scans of medium-format film at a reasonable cost (see "Scanning options" to the right).

Stay away from flatbed scanners with film adapters. While such scanners do a good job on conventional snapshots, they don't produce a scan of sufficient quality for stunning astronomical images. A dedicated film scanner capable of recording at least 12-bit data is a must.

Jason Ware *has been photographing the night sky since 1989 using Meade telescopes. He works as a field application consultant for Synopsys, Inc., a computer-chip-design software provider.*

Obtaining good data

Just as you must properly expose CCD images to capture useable data, you similarly must

/// SCANNING OPTIONS

You can take a great photograph, but if you have no way to convert it to an electronic image your computer can recognize, you won't be able to take advantage of the tips in this story. These four companies will convert your film negative (or color slide) into a high-resolution digital image.

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Ancient Light
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Galaxy Photography Digital Services
www.galaxyphoto.com/dig_serv.htm

Spiegelteam Astrophotography
www.spiegelteam.de

SAGITTARIUS contains several of the finest emission nebulae in the sky. The Lagoon Nebula (M8) sits to the lower right of center, and the Trifid Nebula (M20) is to the upper right. To capture this beautiful scene, the author used images he took through three telescopes. His primary images were made with his 12/16-inch Meade Schmidt camera at f/2.2. He combined two 30-minute exposures on Kodak Technical Pan film through a #92 red filter with four 15-minute exposures on Fuji Superia 100 film. To bring out even more detail, the author then added images taken with his 16-inch Meade Schmidt-Cassegrain telescope at f/10 and his 6-inch Meade 152 ED refractor at f/9.

THE WITCH HEAD NEBULA (IC 2118) in Eridanus lies near Orion's brightest star, Rigel (lower left). To record the faint details of this large nebula, the author took two 15-minute exposures on Kodak PPF 400 print film through his 12/16-inch Meade Schmidt camera at f/2.2.

optimize the process of scanning your negatives to extract all of your film's data. A properly exposed negative or slide contains a great deal of high-quality image data. Extracting it requires more than most scanner software provides.

Although most scanners come packaged with software, I prefer to use *Vuescan* by Hamrick Software. This program gives you greater scanning control. Most importantly, it allows images to be saved at 16-bit resolution.

Such high resolution is essential because we will be "stretching" the data. I'll say more about this in the next section.

All astronomical images are inherently low in contrast. If you start with an image that has as much bit depth as possible, you'll reduce the amount of noise (pixels that were not in the original image) generated when you stretch the contrast with an image-processing program.

Working with histograms

A histogram is a graphical representation of the number of pixels that occupy each level of an image's brightness. Histogram values range from dark (where the value equals zero) to light (where the value equals 65,536 in the case of 16-bit data). A typical astronomical-image histogram will show a gathering of pixels somewhere in the middle of this range.

To stretch this data, you must set the black (zero) point to a value where the dark pixels start to appear on the scale. You also must set the white point to a value just above the histogram's lightest pixels. As an example, let's say the black pixels begin at a value of 15,000, and the white pixels end at a value of 30,000. What does setting the end points of the histogram to these numbers accomplish? Instead of the histogram spanning 65,536 pixels, our new histogram spans 15,000. But the 15,000 pixels occupy the same space as the original 65,536, so we've "stretched" our image's 15,000 pixels by a factor of more than four.

Be careful when stretching a histogram because almost all images contain stars or highlight areas such as galaxy cores that are near the upper end of the scale. If you set the white point too low, you'll "clip" the highlights and lose some of the data. The same is true for the black point, although I prefer a very slight clip of the black point. I've found it combats the effects of light pollution somewhat.

Working with the raw data also lets you use advanced techniques such as opening several copies of the 16-bit file. By doing this, you can optimize the image for shadows, midtones, and highlights separately, then combine them into a single image later. If you used color film to record your image, you'll need to do a histogram stretch for each of the color channels (red [R], green [G], and blue [B]).

Once you've scanned the film, the real fun begins. Image processing of film-based data is much like that of CCD data (without the need for CCD-specific procedures such as dark-frame subtraction or bias frames), and much can be learned from reading books about CCD-image processing. *Photoshop for Astrophotographers*, an e-book on CD-ROM by Jerry Lodriguss is a must for the film astrophotographer, as is *The New CCD Astronomy* by Ron Wodaski.

Two films are better than one

One of the most powerful imaging techniques borrowed from CCD users is "luminance layering." This technique brings out subtle details not possible with color film alone by adding black-and-white film's high resolution.

/// THE END OF AN ERA

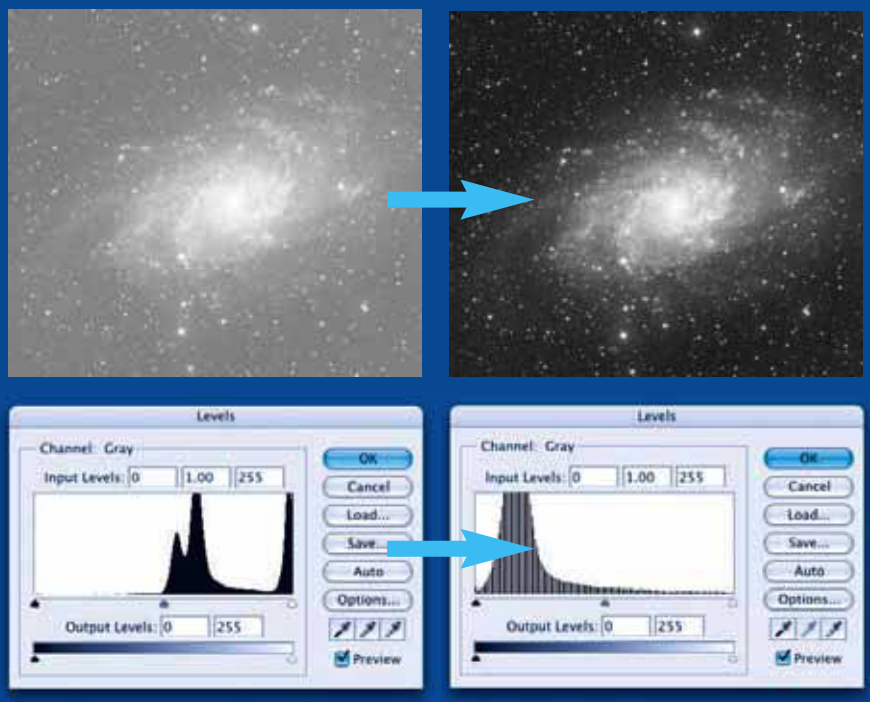
Kodak 2415 Technical Pan film is legendary among astrophotographers. Its low reciprocity failure, extended red sensitivity, and nearly invisible grain made it the top choice for amateurs shooting the Sun, Moon, or planets. Unfortunately, as of April 2003, Kodak discontinued production of this film.

Although Tech Pan was the best, other black-and-white film alternatives exist. In its announcement, Kodak stated, "While there is no direct replacement for Tech Pan film, you may find KODAK PROFESSIONAL T-MAX 100 film in combination with specific black-and-white developers to be a viable alternative for some applications."

After this announcement was made, Lumicon, an astronomical filter and accessories provider, purchased all of Kodak's remaining stock of Technical Pan film in order to secure it for astrophotography purposes. Check with Lumicon at 805.520.0047, or visit its web site at *www.lumicon.com* for price and availability. When stored in a freezer, Kodak 2415 Technical Pan film has a usable life measured in years, so now's the time to stock up.

— Michael E. Bakich

/// HISTOGRAM STRETCHING



Stretching an image's histogram is a way to make the image look better — the ultimate goal of astrophotographers. The original histogram (as displayed in Adobe *Photoshop*) is shown at the lower left. The new, stretched histogram is at the lower right. Note the improvement to the contrast and detail between the original image (upper left) and the new image (upper right). If you're working with an RGB color image, perform a histogram stretch on each of the colors (red, green, and blue) to get the best results.

— Michael E. Bakich

A color electronic image is a combination of luminance (the brightness information) and chrominance (the color information). Indeed, *Photoshop* separates and stores the image data in just this way.

Because this separation is made, the luminance (L) part of a color-film image can be replaced with black-and-white data obtained from an image taken on a different type of film, which provides much higher resolution. This combination of separate (electronic) images forms an "LRGB" image. More details of this process can be found in the image-processing books listed above.

Not dead yet

Although film sales are declining and may eventually go the way of the eight-track tape, there's still a place for this technology in astrophotography. Indeed, until large-format CCD cameras are more affordable, astrophotographers will continue to produce stunning images with film. A

See more of Jason Ware's celestial photography at *www.astronomy.com/toc*

OMEGA CENTAURI is the brightest globular cluster in the sky. It contains more than a million stars, but it's not well-known to northern observers because of its southerly location. To make this image, the author took two 30-minute exposures on Kodak PPF 400 print film through his 16-inch Meade Schmidt-Cassegrain telescope at f/10.

Sometimes, observing is best with both eyes open. /// BY PHIL HARRINGTON

Binoculars under $100

Maybe you're new to the astronomy hobby and thinking about buying a telescope. More often than not, your best first purchase isn't a telescope, but binoculars. Getting used to the narrow, flipped-around images through a telescope can be daunting. Binoculars are more natural, almost like extensions of our eyes. Every amateur astronomer — indeed every person — should own binoculars.

Of course, that begs the question: "Which binoculars?" There are many factors to take into account, but the answer often boils down to budget. It probably makes sense to spend as little as possible to fuel a budding interest.

But just as the marketplace is flooded with low-price telescopes, it is also beleaguered with economy binoculars. You can find dozens out there. Which one is best? Decisions, decisions …

The numbers game

All binoculars are specified by two numbers, such as 7x50 or 10x70. The first number is the magnification, and the second is the diameter of the front (objective) lenses in millimeters. Light passes through each objective lens, reflects through a prism assembly, and then exits through an eyepiece in the form of a magnified cylinder of light called the exit pupil.

Ideally, the exit pupil should match the diameter of your eyes' pupils. If the binoculars' exit pupils are larger than an observer's pupils, light will be wasted.

If, on the other hand, the binoculars' exit pupil is too small, the view will be a circle surrounded by a black ring. Fully dilated, the eye's pupil expands to 7mm, but this varies from person to person.

The diameter of the exit pupil can be calculated by dividing the objective-lens diameter by the magnification. Thus, in the case of 7x50 binoculars, the exit pupil will measure 7.1mm across.

Traditionalists may argue binoculars with 7mm exit pupils are the best for night viewing. That notion probably dates back to World War II, when the U.S. military issued 7x50 "night glasses."

Today, however, most of us view through light-polluted skies under which our pupils never dilate fully. Furthermore, as we age, our pupils don't dilate to the degree they did when we were younger, regardless of darkness.

As a result, many observers prefer 10x50 binoculars because of their 5mm exit pupils. Also, the slightly higher magnification produces better image contrast (the bright-to-dark ratio) than through a 7x50, and the 10x50 model is still light enough to support by hand.

Some observers prefer larger binoculars because they offer increased light-gathering power. The increased size and

ALL IMAGES ASTRONOMY: WILLIAM ZUBACK

Orion Scenix

Bushnell Legacy

Eagle Optics Triumph

/// FIND THE RIGHT BINOCULARS FOR YOU

Model	Price	Magnif. (x)	Aperture (mm)	Field of view (°)	Exit pupil (mm)	Eye relief (mm)	Weight (ounces)	Prisms	Coatings
Bushnell Legacy	$99	10	50	7.2	5.0	9	28	BaK-4	MC
Celestron OptiView LPR	$100	10	50	7.0	5.0	13	32	BK-7	FC
Celestron SkyMaster	$88	15	70	4.4	4.7	18	48	BaK-4	MC
Celestron UpClose	$37	10	50	7.0	5.0	11	25	BK-7	FC
Eagle Optics Triumph	$99	10	50	6.5	5.0	19	30	BK-7	FC
Nikon Action	$100	10	50	6.5	5.0	12	34	BaK-4	MC
Oberwerk 8x56	$100	8	56	6.0	7.0	24	32	BaK-4	FMC
Oberwerk 11x56	$100	11	56	4.0	5.1	19	32	BaK-4	FMC
Orion Scenix	$90	10	50	7.0	5.0	12	28	BaK-4	FC
Orion WorldView	$40	10	50	6.5	5.0	14	29	BK-7	FC
Pentax XCF	$90	10	50	6.5	5.0	13	31	BaK-4	MC
Swift Aerolite	$81	10	50	5.2	5.0	13	37	BK-7	FC
Tasco Sonoma	$60	10	50	6.5	5.0	9	23	BK-7	MC

Coatings:
FC: Fully coated optics
MC: Multicoated optics
FMC: Fully multicoated optics

weight, however, is difficult to support by hand — especially for extended lengths of time — and requires a tripod.

Maximizing light throughput

When evaluating binoculars, it's also important to consider glass and coatings. Although optical glass usually is thought of as transparent, it can reflect up to 4 percent of any light falling on it.

To lessen this percentage and improve image quality, an antireflection coating (usually of magnesium fluoride) is applied to either some or all air-to-glass

Pentax XCF

Celestron SkyMaster

Orion WorldView

surfaces of binocular lenses. While a single coating is good, multiple thin coatings are even better at enhancing the unit's optical performance.

So-called multicoated binoculars, however, typically have only the outer lens surfaces coated. For the best views, all surfaces should be coated, so "fully coated optics" is preferred. "Fully multicoated" optics, where every optical surface has been coated with several microscopically thin layers of magnesium fluoride, is your best choice.

Better binoculars use prisms made from barium crown (BaK-4) glass, while lesser models use borosilicate (BK-7) glass. BaK-4 prisms transmit brighter, sharper images because their design passes all the light that enters — what's known as "total internal reflection." Due to their optical properties, BK-7 prisms suffer from light fall-off and, consequently, slightly dimmer images.

Besides their optical qualities, binoculars should be comfortable to look through and hold. You shouldn't have to hold binoculars far in front of your eyes or scrunch them in close to take in the full field of view.

The distance between the eyepieces and your eyes is called eye relief, and it is usually expressed in millimeters. The binoculars featured here have eye relief ranging from 9mm to 24mm. If you must wear glasses when observing, stick to the high end of the range.

All of the binoculars here have over-the-counter prices of $100 or less and are readily available from local merchants or by mail order. All come with the same basic accessories, including soft carrying cases, neck straps, and, in most cases, a lens-cleaning cloth.

All are center-focus models. This means when you turn a knurled dial, both eyepieces focus simultaneously, rather than each eyepiece being focused individually.

But what if your eyes don't come to the same focus? Not to worry. The right eyepiece on each of these binoculars can be focused independently of the center focus mechanism. The table on page 71 summarizes each binoculars' statistics and features.

Testing with both eyes

To find out if some binoculars are better than others, I tested them head-to-head. I checked for optical aberrations during the day as well as at night.

Field curvature and distortion are checked most easily during the day on terrestrial targets. Distortion causes straight lines to bow or curve, while field curvature causes different parts of the view to focus at different settings.

Viewing celestial objects at night will give you a pretty good indication of binoculars' image brightness, astigmatism, and contrast.

Phil Harrington *is the author of the new observing guidebook* Star Watch, *which is published by John Wiley & Sons.*

Oberwerk 11x56

Oberwerk 8x56

Astigmatism, which causes stars to focus as extended lines rather than points, is most noticeable in the periphery (edges) of the field of view.

So, how did they perform? All of the binoculars showed some degree of each aberration but performed surprisingly well considering their low prices.

I judged the Orion Scenix 10x50 ($90) a cut above the rest for excellent image contrast and brightness. Focusing is smooth and precise, and images are sharp and clear. Distortion and field curvature are evident around the outer 25 percent of the field of view, which is less than most in this price range. The view through the Scenix 10x50 compared favorably to my Orion UltraView 10x50 binoculars, which cost $70 more.

The Nikon 10x50 Action binoculars ($100) also are exceptional. Aberrations are well-corrected, as evidenced by a sharp, flat field of view and good image contrast. I also like Nikon's bayonet-style eyecups that twist out rather than fold like all the others. Ergonomically, the binoculars have a sculpted feel that makes holding them easy.

Images through the Bushnell 10x50 Legacy ($99) and Pentax 10x50 XCF ($90) binoculars are as bright as in the Nikon 10x50, although the Bushnell and Pentax models have a bit less image contrast. Distortion and astigmatism also are more pronounced than through the Nikons, blurring the outer third of each field. Both the Bushnell and Pentax binoculars are easy to hold, however, and focus smoothly.

Swift Aerolite

Tasco's Sonoma binoculars ($60) also have good image brightness and contrast. Field curvature, however, softened the outer half of the field of view when the inner half was focused, and vice versa. Ergonomically, I found the Sonoma's tapered eyecups to be the most comfortable as well as the most effective at blocking stray light. The eyecups worked well even when I purposely observed near a streetlight. The binoculars I tested had traditional multicoated optics, but many retailers sell a different version that includes ruby-coated lenses. Ruby coatings, designed to reduce glare in bright lighting, are not suitable for stargazing.

Images in the Oberwerk 11x56 binoculars ($100) also were sharp, although I saw some minor ghosting (the appearance of faint, duplicate images) around brighter objects. The ghosting is likely an artifact caused by irregularities in the paint inside the barrels of the particular binoculars I tested. Several spots around the internal field stop looked as though they had been touched up with less-than-flat black paint. Focusing, however, was smooth, and the unit was comfortable to hold thanks to conical barrels.

Not only do the Oberwerk 8x56 binoculars ($100) look the same as the 11x56 model, but the field of view is practically the same. While 6° is a wide field of view for 11x binoculars, it's a bit

Nikon Action

Tasco Sonoma

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Celestron OptiView LPR

narrow for 8x. The small field creates a noticeable tunnel-vision effect I found confining. Even though the image contrast is good, and stars are sharp across 80 percent of the field, I preferred the 11x56s for the above reason.

The Celestron OptiView LPR ($100), Orion WorldView ($40), and Eagle Optics Triumph 10x50 binoculars ($99) all produce good image brightness and contrast, although not quite to the level of the previous models. All had sharp images across the inner 75 percent of their fields of view as well as acceptable contrast and sharpness. And here's a twist: Celestron's OptiView binoculars have built-in broadband light-pollution filters. Turning small thumbwheels at the base of the prism housing swings the filters in and out. Urban stargazers might benefit from this feature, but I didn't see a big difference from suburban or rural settings.

While Swift's Aerolite binoculars ($81) are comfortable to hold, the thin focus wheel is a little more difficult to use than the focusing wheels on the other binoculars. Contrast is good, although image brightness isn't as high as through some of the other models. The outer third of the field of view also produced soft images due to field curvature. The Aerolites also are the only binoculars I tested without a tripod socket built into the central hinge.

Celestron's 10x50 UpClose binoculars ($37) are the least expensive in this group. Despite the low price, images are more than satisfactory for someone just starting out. Admittedly, contrast is lower and astigmatism is greater than in some other models. However, providing beginning observers fully coated optics for under $40 is a great manufacturing accomplishment.

Finally, we come to Celestron's giant 15x70 SkyMaster ($88), which I left to the end because their size puts them in a different league than the rest. Image brightness, quality, and contrast are all remarkable considering the bargain price. Usually, you should mount binoculars of this size on a tripod to get the most out of them, but I was able to hold the SkyMaster by hand long enough to enjoy views of many of my favorite sky objects. Although images were a little soft across the outer 25 percent of the field, the overall effect was striking. If you are in the market for giant binoculars at an economical price, I recommend Celestron's 15x70 SkyMaster binoculars.

Indeed, all of the binoculars presented here offer exceptional value for the money. As in the telescope market, binoculars that contain advanced features are readily available at amazingly low prices. The models featured here certainly prove you don't need to break the bank for binoculars that will serve you well for years to come. A

Celestron UpClose

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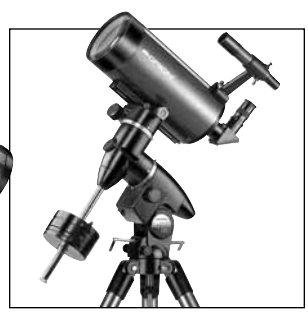

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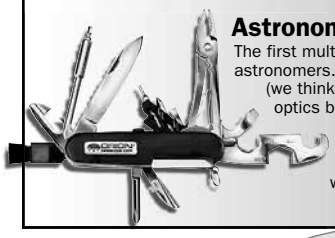

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RESOURCES

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QUEST FOR A LIVING UNIVERSE

BOOKS — *An Introduction to Astrobiology*, edited by Iain Gilmour and Mark Sephton (New York: Cambridge University Press, 2004), covers everything from the chemistry of living organisms to exoplanets and search methods.

Life's Origin, edited by J. William Schopf (Berkeley, California: University of California Press, 2002), is a collection of essays written for those interested in how (and when) life got started on Earth.

For a history of how the fields of exobiology and astrobiology got started, see *The Living Universe: NASA and the Development of Astrobiology* by Steven J. Dick and James E. Strick (New Brunswick, New Jersey: Rutgers University Press, 2004).

If you know a child who's interested in the subject, check out *Are We Alone?* by Gloria Skurzynski (Washington: National Geographic Society, 2004).

WEB — For more information about life in the universe and the search for it, visit NASA's site, *astrobiology.arc.nasa.gov*.

See *science.uniserve.edu.au/school/quests/hydroventwq.html* for more on "black smokers." This page also provides links to sites dealing with every aspect of these underwater features.

Thomas Gold's ideas on the deep biosphere are on-line at *people.cornell.edu/pages/tg21/DHB.html*. He also wrote a book about the concept, *The Deep Hot Biosphere* (New York: Copernicus Books, 1999), which presents his hypothesis in greater detail.

For more on the lunar cataclysm and its effects on both the Moon and Earth, see *www.lpl.arizona.edu/SIC/impact_cratering/lunar_cataclysm/Lunar_Cataclysm_Page*.

HUYGENS' DESCENT TO TITAN

ARTICLES — Read Richard Talcott's "Cassini targets Titan" (*Astronomy*, February 2005) for more on the spacecraft's arrival at the moon and its first close-up images.

Talcott's "Cassini reaches Saturn" (*Astronomy*, October 2004) covers the spacecraft's historic arrival at the ringed planet.

WEB — NASA's page on the Cassini orbiter is at *saturn.jpl.nasa.gov/index.cfm*. The European Space Agency's site for the Huygens probe is at *sci.esa.int/science-e/www/area/index.cfm?fareaid=12*.

DARKER THAN THE NIGHT

BOOKS — For those who want to delve deeply into galaxies, the place to go is *Galaxy Morphology and Classification* by Sidney van den Bergh (New York: Cambridge University Press, 1998). He devotes a chapter each to low-surface-brightness galaxies and dwarf galaxies.

ARTICLES — For the latest on the Local Group of galaxies, including the importance of our small cluster's extensive collection of low-surface-brightness dwarf galaxies, see "Order out of chaos" by Ray Villard (*Astronomy*, November 2003).

Villard also wrote about the plans for the Large-aperture Synoptic Survey Telescope (LSST) in "Unveiling the dark universe" (*Astronomy*, November 2002).

SEEKING THE FIRST GALAXIES

ARTICLES — Learn more about astronomers' first impressions of the Hubble Space Telescope's Ultra Deep Field (HUDF) in "To the cosmic edge," by Frank Sietzen, Jr. (*Astronomy*, July 2004).

WEB — Take a personal tour of the HUDF with GEMS Skywalker, an on-line tool that gives you a wide-field, modest-resolution look at the entire image at *www.aip.de/~ssa/gems/sw/index.php*.

Do you want to go deeper? Check out UDF Skywalker for high-resolution views at *www.aip.de/groups/galaxies/sw/udf/index.php*.

ASK ASTRO

WEB — Physicist Clifford Will of Washington University explains why the Jupiter experiment says nothing about the speed of gravity at *wugrav.wustl.edu/people/CMW/SpeedofGravity.html*.

Join the search for gravity waves with Einstein@Home, *einstein.phys.uwm.edu*. This screen saver uses your computer's idle time to search data from the LIGO and GEO gravitational wave detectors. The goal: to sense gravity waves from spinning neutron stars.

SHARPER PHOTOS WITH FILM

BOOKS — In addition to the two books mentioned in the story, check out Michael Covington's *Astrophotography for the Amateur* (New York: Cambridge University Press, 1999). It's a good starting point for beginners and an excellent reference for advanced astrophotographers.

Astrophotography: An Introduction to Film and Digital Imaging by H. J. P. Arnold (Toronto: Firefly Books, 2003) is a beginner's guide with examples of the celestial objects you'll most want to photograph.

WEB — To keep abreast of the latest news, consider joining the Astro-Photography Mailing List (APML), an Internet-based mailing list dedicated to film-based photography. Get more information at *http://astro.umsystem.edu/apml*.

BINOCULARS UNDER $100

BOOKS — Observe the night sky with your binoculars using Phil Harrington's *Touring the Universe through Binoculars* (Hoboken, New Jersey: John Wiley, 1990). This book, a constellation-by-constellation guide, lists both the capabilities and limitations of binoculars on each celestial object.

Concentrate on our nearest celestial neighbor with *Exploring the Moon through Binoculars and Small Telescopes* by Ernest Cherrington, Jr. (New York: Dover Publications, 1984).

Finally, *Exploring the Night Sky with Binoculars* by Patrick Moore (New York: Cambridge University Press, 2000) is a book for beginners that highlights easily seen double and variable stars. A

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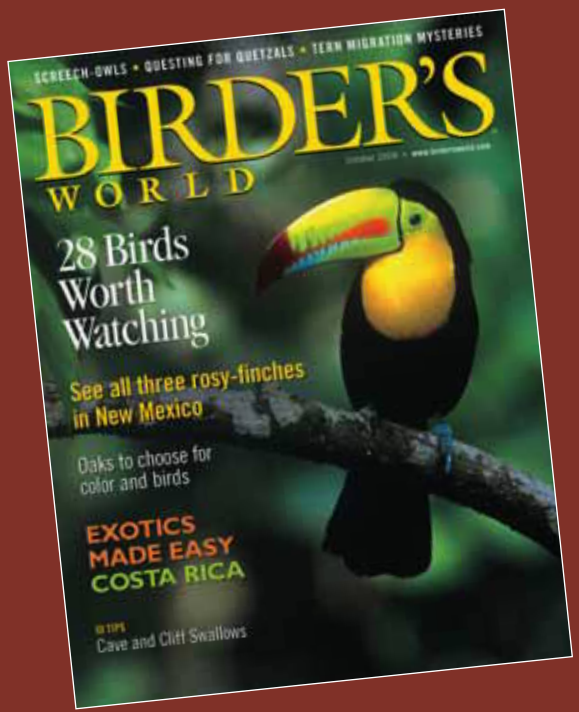

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76mm APO Doublet 480mm, f/6.3 Green Tube Kit #GXC-3063..........1675.00
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Tele-Pod Mount with Head 395.00	Ashwood Panoramic Mount 540.00
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55mm 2”..........228.00	40mm, 32mm 1.25” 110.00
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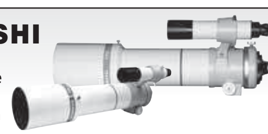

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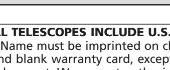

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Buzz on space
Astronaut Buzz Aldrin speaks with *Astronomy* about walking on the Moon, the future of space exploration, and the role of private enterprise in space flight.

A family affair?
Astronomers long believed open and globular star clusters were entirely different beasts. Yet new research suggests that, in some cases, the two could be intimately linked.

Inside a pinwheel
Within the confines of Ursa Major lurks a galaxy that's easy to find but not so easy to observe. Read our profile of M101, and you'll see more detail in this galaxy than ever before.

Imaging on a budget
What do you really need to spend to capture great images of the Sun, Moon, and planets? Noted astroimager Damian Peach explains how you can create great images with a telescope as small as 3 inches.

StarStructure Dob
Large telescopes are really heavy, right? Not necessarily. A new Dobsonian by StarStructure Telescopes is easy to assemble, has great optics, and weighs 20 pounds less than comparable scopes.

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APRIL 6–9, 2005

The Mid-South Star Gaze calls

skywatchers throughout the southeastern United States to the Rainwater Observatory and Planetarium in French Camp, Mississippi. The annual star party offers amateur astronomers a chance to observe under a dark

THE MID-SOUTH STAR GAZE tempts observers with a clear, dark sky, but it also offers various lectures and workshops held at the site's amphitheater and covered pavilion. TERRY ATWOOD

sky, compare instruments, and share tips with fellow astronomy aficionados.

While observing draws most of the attendees, others will come for the strong roster of speakers. This year, the Mid-South Star Gaze presents lectures covering topics from astroimaging, to space science, to cosmology.

For more information, call the Rainwater Observatory at 662.547.6377; e-mail, info@rainwaterobservatory.org; web site, *www.rainwaterobservatory.org/stargaze*.

APRIL 6–8, 2005

International Dark-Sky Association Annual Meeting

Hilton Hotel, Tucson, Arizona. This year's gathering will concentrate on "Vision at Night." Participants from various disciplines, such as architecture, psychology, biology, and computer science, will discuss light-pollution issues. For more information, e-mail ida@darkskyorg; web site, *www.darksky.org*.

APRIL 7–10, 2005

Southern New Mexico Star Party

City of Rocks State Park, Faywood, New Mexico. Hosted by the National Public Observatory, this biannual event is held at a remote, scenic state park with an elevation of 5,500 feet (1,676 meters), ensuring dark skies. For more information, visit *astronomy-national-public-observatory.org*.

APRIL 8–10, 2005

Desert Starlight

Brantley Lake State Park, Carlsbad, New Mexico. During the daytime, rangers will lead nature tours through the grounds, showcasing the geology and ecology of the region. For more information, visit *www.livingdesertastronomy.com*.

APRIL 8–10, 2005

South Jersey Spring Star Party

Belleplain State Forest, near Woodbine, New Jersey. This "no-frills" event is held at

one of the premier dark-sky sites in the region. For more information, visit *hometown.aol.com/sjastroc*.

APRIL 16, 2005

AstroDay 2005

Prince Kuhio Plaza, Hilo, Hawaii. Held in a popular mall, AstroDay brings astronomy to thousands of people each year through activities and displays. For more information, e-mail fujmon@mac.com; web site, *www.astroday.net*.

APRIL 16, 2005

ScopeX

South Africa Military History Museum, Johannesburg, South Africa. This event promotes astronomy to the people of Johannesburg and introduces telescope making. For more information, visit *www.aqua.co.za/assa_jhb/new*.

APRIL 16–17, 2005

Northeast Astronomy Forum and Telescope Show

Rockland Community College, Suffern, New York. This annual gathering features exhibits and lectures by prominent astronomers, including Wil Tirion and Phil Plait. *Astronomy* senior editor Rich Talcott will attend. For more information, visit *www.rocklandastronomy.com*.

APRIL 22–23, 2005

NIAGfest

Camp Crosley, North Webster, Indiana. Cosponsored by the Northern Indiana Astronomical Group and the Great Lakes Region Astronomical League, NIAGfest is a weekend of camping and observing. For more information, visit *www.clubs.kconline.com/was/niag.htm*.

APRIL 22–23, 2005

North Central Region of the Astronomical League Star Party and Convention

John and Helen Collins Learning Center and Leif Everson Observatory, Sturgeon Bay, Wisconsin. Any member of an astronomy group in this region is encouraged to attend. The meeting will feature exhibits, workshops, and lectures, including one by astroimager Don Parker. For more information, visit *www.npmas.com*.

MAY 4–8, 2005

Desert Sunset Star Party

Caballo Loco Ranch RV Park, near Tucson, Arizona. The Whipple Observatory will offer a day-long tour the Friday during the star party. For more information, visit *chartmarker.tripod.com/sunset.htm*.

MAY 6, 2005

Far Out Friday

Adler Planetarium and Astronomy Museum, Chicago. On the first Friday of every month, the Adler hosts an evening of astronomy-related fun, including observing, lectures, and tours of the facilities. For more information, visit *www.adlerplanetarium.org*.

MAY 20–23, 2005

Royal Astronomical Society of Canada General Assembly

Okanagan University College, Kelowna, British Columbia. This convention will feature exhibits, a tour of the Dominion Radio Astrophysical Observatory, and lectures by leading figures in astronomy, including space-telescope scientist Jaymie Matthews. For more information, visit *www.ocrasc.ca/ga.html*.

MAY 27–29, 2005

Riverside Telescope Makers Convention

YMCA Camp Oakes, near Big Bear City, California. The location is a high-altitude site in the San Bernardino mountains. This year's theme is "The History of Astronomy." For more information, visit *www.rtmcastronomyexpo.org*.

CONTACT INFORMATION

Please submit club announcements 4 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our on-line calendar.

INDEX *of* ADVERTISERS

20/20 Telescopes 90
Adorama 82, 83
Anacortes Telescope and Wild Bird 19
Analytical Scientific 91
Ash Manufacturing 27
Astro Haven 90
Astro Physics 75
Astrographics Publishing 27
Astronomics 86-87, 90
Astronomy.com 27
Astronomy magazine 84
Astronomy magazine Tour to Hawaii 27
Astronomy magazine Tour to Machu Picchu 82
Astronomy magazine Tour to Tahiti 79
Atomic Time 61
Birders World magazine 81
Beam of Light Technologies 61
Bennett Book Advertising 23
Berger Brothers Camera 89
Beta Electronics 90
Bethany Sciences 89
Binoculars.com 88
CStar Optics, Inc 88
Camcor, Inc 79
Camera Bug 89
Coronado Instrument Group 7
Dark Sky, Inc 89
Davis Instruments 61
Denkmeier Optical 88
Equatorial Platforms 89
Focus Camera 23
Galaxy Piers 88
Galileo Optics 88
Glatter, Howard 75
Into the Wind/The Kite Source 89
Jim's Mobile Industries 21
Lumicon 15
Marketplace Pages 88-91
Meade Instruments Corp 2, 3, 8, 9, 98
Midwest Optics 88
New Mexico Skies 90
Northeast Astronomy Forum 61
Observatory, Inc. , The 90
Oceanside Photo & Telescope 17, 89
Orion Telescopes & Binoculars 76-77, 97
Pegasus Optics 91
Rainbow Symphony 90
Ritz Camera Superstores 88
Rivers Camera Shop 75
SAC Imaging Systems 88
SCS Astro 88
Scope Buggy 75
Scope City 21
Scope Stuff 90
ScopeTronix 13
Shutan Camera & Video 79
Sirius Observatories 91
Sky Watchers Inn 89
Smartcase Designs 90
Software Bisque Inc 35
Solarscope 91
Star Hill Inn 91
Stargazers Inn 90
Star GPS 88
Starquest and Recreation 91
Stellarvue 89
Stephen L Geller Inc 25
Streamtrade International 89
Technical Innovations 23
Tele Optics 90
Televue Optics, Inc 10-11
Website Directory 92
Woodland Hills Photo Images 92
www.bigbinoculars.com 90
Yankee Robotics 91
Zerpec, Inc. 88

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We started ***astronomics*** over 25 years ago because we loved astronomy, not just as a business. Our sales may have grown over a thousand-fold since that first year, but we're still the same family-owned, family-run, full-line telescope dealer we were in 1979. And we still love astronomy.

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You can get the Meade telescope you want shipped from our stock . . . right now . . . at the right price . . . right here at ***astronomics.***

Meade LX200GPS telescopes have a GPS system to align your telescope on the sky *automatically*. You start observing in mere minutes.

Their feature-laden Autostar computers find and track over 145,000 stars and objects for you *automatically*. You spend more of your time looking *at* heavenly bodies and less time looking *for* them.

Smart Mount Technology improves your scope's pointing accuracy as you observe. A Lunar Planetary Imager takes digital color pictures for you. Optional UHTC optics increase the light transmission by an average of 15%.

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Here are the Meade LX200GPS telescopes that we ship from our stock via Fedex ground:

7" Maksutov-Cassegrain ..... **$2695**^{00}
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8" Schmidt-Cassegrain ..... **2195**^{00}
8" Schmidt-Cassegrain, w/UHTC ..... **2370**^{00}
10" Schmidt-Cassegrain ..... **2745**^{00}
10" Schmidt-Cassegrain, w/UHTC ..... **2980**^{00}

Here are the scopes Meade ships from the factory via motor freight due to their weight:

12" Schmidt-Cassegrain ..... **$3595**^{00}
12" Schmidt-Cassegrain, w/UHTC ..... **3890**^{00}
14" Schmidt-Cassegrain ..... **4995**^{00}
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New lower prices on all 16" models!

16" SCT, w/altazimuth pier and UHTC ... **10,639**^{00}
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I just recently purchased a SBIG ST-10 camera from your store and am very delighted with it, though I have yet to test all features. It made me think back to when I purchased a DS-10 from you back maybe 20 years.

I just wanted to thank you and congratulate you for developing and running such a good store. You have really helped me enjoy astronomy.

Anyway, thanks for all the help over the years. You always provided that which I could not get locally. For that I thank you.

Customer Quote of the Month #157

Meade LXD75 go-to scopes make astronomy easy.

6" Meade SN-6 AT Schmidt-Newtonian **$799**

Even if you're not familiar with the skies, you won't spend all of your time hunting for deep space wonders with a go-to **Meade LXD75** reflector, refractor, or Schmidt-Cassegrain.

A few touches on the Autostar computer of an LXD-75 speeds you to any of more than 30,000 stars, planets, and deep space objects, then tracks it accurately for as long as you want to observe. You spend more of your observing time actually looking *at* celestial objects and less time looking *for* them with a Meade LXD75.

8" Meade SC-8 AT Schmidt-Cassegrain **$1299**

Each has an adjustable height steel leg tripod, dual motors, finderscope, eyepiece, illuminated polar finder, Autostar computer to take the guesswork out of finding your way around the skies, and a Lunar Planetary Imager color digital camera.

Big binoculars. Bright images. Little prices.

$349

You don't need a telescope to enjoy astronomy. Many deep space sights – nebulas, galaxies, star clusters – are all visible through large aperture binoculars . . . as are myriad craters, and mountains on the Moon.

**$99**^{95}

The **Celestron 10 x 50mm LPR Optiview**, left, is a good conventional binocular that has a secret weapon for astronomy – built-in light pollution filters to block the glare of city lights that can wash out faint nebula and galaxy detail.

The **Celestron 25 x 100mm Skymaster**, right, gathers as much light as two 4" telescopes, one for each eye. It and the similar but smaller aperture **20 x 80mm Skymaster** at $259 (whose light-gathering equals two 3.1" scopes) gather huge amounts of light for wide angle views of open star clusters, nebulas, and galaxies.

Meade's 20 new Series 5000 eyepieces.

There are 20 new **Meade Series 5000** eyepieces available in three different advanced optical designs.

The seven new 60° field 1.25" and 2" Plössls use unique five and six lens optical designs. Prices start at $89.

The six new six-lens 68° field 1.25" and 2" Super Wide Angles start at $179.

The seven new 82° field 1.25" and 2" Ultra Wide Angles use six and seven lens optical designs and start at $199.

All have long eye relief, twist-up eyecup, and very good images.

A William Optics ZenithStar *apo* refractor for only $485.

The **William Optics ZenithStar 66** is a true *apochromatic* refractor at a sensationally low price. Three-element 66mm f/6.2 optics, 1.25" rack and pinion focuser and image-erecting diagonal, 20mm wide angle eyepiece, retractable lens shade, soft carry bag. Its L-shaped mounting shoe fits either a photo tripod or an SCT piggyback. Use it as a super finder for your main scope or as a second scope for astronomy, travel, or birding.

$485

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Celestron Dobs are nifty, inexpensive, and *in stock.*

Celestron StarHopper Dobsonians use roller bearings riding on a broad azimuth track for smooth hitch-free horizontal motion. Nylon roller altitude bearings provide an equally smooth vertical motion.

8" f/6 StarHopper **$349**

The finder (a 6 x 30mm on the 6" and a 9 x 50mm on the 8" and larger scopes) is mounted in an easy-to-align quick release bracket. 8" and larger scopes have a 2" metal rack and pinion focuser (with a 1.25" eyepiece adapter). A 2" 32mm E-Lux eyepiece is standard. The 6" scope has a 1.25" metal rack and pinion focuser and comes with a 25mm 1.25" Plössl.

The 10" and 12" scopes have a battery-operated fan for cooling their primary mirrors. All have fast cool-down metal tubes and BK7 optical glass mirrors.

Here are the prices for the fully-equipped Celestron StarHopper Dobsonians.

6" f/8 StarHopper ..... **$249**^{00} + $59 freight
8" f/6 StarHopper ..... **349**^{00} + $69 freight
10" f/5 StarHopper ..... **499**^{00} + $79 freight
12" f/5 StarHopper ..... **849**^{00} + $129 freight

Big right angle finders . . . at not very big prices.

Antares 7 x 50mm and 12 x 80mm right angle finders are priced from $79^{95} to $184^{95}. Choose from Celestron black, Meade blue, or gloss white in either standard mirror-image or erect right-reading models that show you the sky the way it appears on star charts. Economical optional quick release mounting brackets are available.

**$184**^{95}

Want to read *unbiased* equipment reviews by astronomers just like you? Find them at www.cloudynights.com

A Premier ETX is almost as easy as GPS!

ETX-125PE **$1095**

Each new Premier Series **Meade ETX** 3.5" to 5" Maksutov-Cassegrain has *Level North Technology* to make it easy to align your scope on the sky.

Simply tell the ETX your zip code or location. It levels its optical tube (a full color deep space image decorates the tube), finds North, sets the time, and moves to its alignment stars – *all automatically!* Center the new wide-field red dot finder on the alignment stars and start observing. That's all it takes. Using an ETX is almost as easy as using a GPS system, but a new ETX Premier costs a lot less!

The Meade LX90-LNT – new scope, old price.

It's not often that you get a significant upgrade to a product without an equally significant price increase. But Meade has just done it with the new LX90-LNT.

The 8" **Meade LX90-LNT** Schmidt-Cassegrain has *Level North Technology* to make aligning your scope on the sky easier than ever. Simply tell it your zip code or location. The scope levels its optical tube, finds North, sets the time, and moves to its first alignment star – *automatically!* Center the red dot finder on the alignment stars (you still get an 8 x 50mm finder), and start observing. It's almost as easy to use as a GPS system, but it costs no more than the previous LX90!

$1695

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This month's hot new products . . .

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The **Meade** 10" through 16" Ritchey-Chrétien telescopes put the same premium optical design used in the Hubble Space Telescope into affordable and portable telescopes for the amateur astronomer. Known for a wide coma-free field that's perfect for astrophotography, the Ritchey-Chrétien design is the telescope of choice in many professional observatories, including Hawaii's twin 10-meter Keck telescopes.

The big and fast f/8 Meade Ritchey-Chrétiens are available in four sizes:

The 10" **RCX400 10"** **$4999.00**
The 12" **RCX400 12"** **6599.00**
The 14" **RCX400 14"** **8999.00**
The 16" **RCX400 16"** **15,999.00**

Each has a full aperture correcting lens to reduce residual astigmatism so that stars are crisp and point-like across the entire field. GPS and Level North Technology make aligning on the sky *automatic*. You start observing in minutes. High Precision Pointing, UHTC optics for a 15% increase in light transmission, Permanent Periodic Error Correction, a 2" UHTC star diagonal, a 2" 24mm Ultra Wide eyepiece – the list of features just goes on and on.

$6599
Meade 12" f/8 RCX400 Ritchey-Chrétien

21st century Celestron go-to . . . a 1984 price.

If you fondly remember the original orange-tube C8, the new 8" **Celestron NexStar 8i Special Edition** will bring back the good old days – at a low price that's straight out of the 1980s!

This limited production SCT combines a modern anodized version of Celestron's vintage orange and black paint scheme, the convenience of a go-to computer, and the bright images of Starbright XLT – Celestron's best multicoated optics ever.

The best part? This 21st century telescope is available for less than the price of an 8" Celestron from 1984 that didn't even have a computer.

Telescopes have changed a lot over the past 20 years. But the value and optical performance of a Celestron C8 have always been standards you can rely on.

$1399

A free case with this JMI binocular telescope.

Through April 30th, you get a $399.95 carrying case for *free* when you buy the 6" JMI RB66 binocular telescope.

The RB66 lets you look down in comfort with both eyes to see the sky. You see more contrast and up to 40% more lunar, planetary, and deep space detail than when you squint through a conventional telescope eyepiece with one eye.

6" JMI RB66 binocular telescope
$2995

Its two 6" f/5 mirrors gather as much light as an 8.5" rich field reflector. Two 20mm eyepieces (1.4° field), electric focusing, electric collimation, and a StarPointer red dot finder are standard.

One of our long-time customers said of the RB66, "Finally I am seeing objects in the way I have always wanted to view them, with both eyes using a wide field of view. It is like looking through a huge, magnified picture window."

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If you want to keep TeleVue customers happy, you have to keep a lot of TeleVue in stock so you can ship fast. We *do* keep a big inventory on hand, so our customers are *very* happy. Others may *say* they carry TeleVue, *but we actually keep TeleVue in stock.* Lots of it.

NP-101 **$3595**

Here are a few of the TeleVue refractors we stock for immediate shipment.

TV-60, 2.4" f/6 apo **$795.00**
TV-76, 3" f/6.3 apo **1275.00**
TV-85, 3.35" f/7 apo **1680.00**
TV-102, 4" f/8.6 apo **2200.00**

All of these refractors are basic optical tubes, with dust covers and a carrying case only. Complete optical tubes, with a star diagonal, Plössl eyepiece, mounting ring, dust covers, and carry case are also available from stock.

As for accessories, we keep them all. Gibraltar, Panoramic, Tele-Pod mounts; Sky Tour computers for those mounts; Nagler, Radian, Panoptic, Plössl eyepieces; Powermates and Barlows; Everbrite 99% reflectivity dielectric star diagonals; light pollution filters; and more. Whatever TeleVue you need, we probably have it in stock.

There's nothing mysterious about *this* Sphinx.

Vixen Sphinx telescopes and mounts take the mystery out of go-to astronomy. You don't have to know Messier, NGC, or IC numbers to find things in the sky.

Simply move a cross-hair cursor over an object displayed on the 4096-color LCD star chart screen of the Sphinx Star Book hand control. Push a button and the Sphinx mount moves your scope to the object. Zoom buttons on the chart display control the motor speed. Zoom in on an object on the screen and the motors slow for more accurate control. Zoom out and the motors speed up to cover large distances more quickly.

Vixen Star Book hand control showing star chart display

You can update the Star Book's 4MB flash ROM memory from the Internet to keep you current with the heavens. And the easy-to-use Star Book can be used as a stand-alone star atlas so you can learn the skies anywhere, anytime.

$3250
ED80SWT-SXW 3.1" f/9 ED apo Vixen refractor on Sphinx go-to mount

The Sphinx go-to mount with Star Book controller is available separately for use with your own optics. It is also available in premium Vixen telescope/mount packages that range from a 3.1" refractor to big 8" reflectors and catadioptrics.

Vixen Sphinx details and prices are on our **www.astronomics.com** website.

Meade Deep Sky Imager (DSI) for $299.

The **Meade Deep Sky Imager** takes color deep sky photos at a fraction the cost of a CCD camera. Use it with any scope to take photos of galaxies, nebulas, and star clusters – plus the Moon and planets.

The easy-to-use Meade Deep Sky Imager includes the Autostar Software Suite of planetarium and imaging control software and the USB cables needed to connect the imager to your laptop computer or PC. Best of all, the entire package is all yours for only $299!

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If you find a lower nationally advertised price on any in-stock product we sell, either in this magazine or on a telescope or camera store's website (chain stores excluded), let us know when you order. We'll meet or beat any delivered price.

Celestron 11" scopes start at only $1699.

The 11" Celestron **Advanced Series** Schmidt-Cassegrains make big aperture astronomy affordable. With almost twice the light-gathering of an 8" scope, an 11" shows you more deep space wonders than an 8" – *for about the same price.*

The 11" Advanced Series telescopes available from our stock include:

C11S on an equatorial mount **$1699.00**
C11S with XLT coatings **1979.00**
C11S-GT go-to equatorial **1999.00**
C11S-GT go-to with XLT coatings **2279.00**

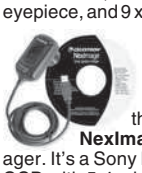
The C11S and C11S (XLT) have a German equatorial mount, adjustable height tripod with 2" steel legs, slow motion controls, setting circles, 40mm Plössl eyepiece, and 9 x 50mm finder. Starbright multicoatings are standard on the C11S. XLT multicoatings on the C11S (XLT) give you 16% more light. An optional dual-axis drive is available.

The C11S-GT and GT (XLT) go-to models add dual motor drives and a NexStar computer to automatically find over 45,000 stars and objects for you.

At only 29 lbs for the heaviest piece, they are easy to transport and set up. And, best of all, they are very affordable. A big scope no longer costs a fortune, thanks to Celestron.

11" Celestron C11S
$1699

Celestron's NexImage captures the solar system for only $99.



There's a true CCD at the heart of the **Celestron NexImage** Solar System Imager. It's a Sony HAD full color 640 x 480 CCD with 5.4 micron pixels. It takes high power lunar/planetary images with any brand or size telescope and sends them to your computer to view live or print out later. At only $99, it makes serious solar system imaging affordable for everyone.

Some nifty accessories to make your observing easier.

Red night vision flashlights protect your dark-adapted vision while you're observing. **Celestron's** variable brightness flashlight (our part #VLED) is **$21.95**.

The **Rigel Systems** variable brightness light shown (our #4591) is **$24.95**. Rigel's 2-color variable brightness light (#4592) – red for reading star charts, blue-white for setting up or taking down your scope – is **$29.95**.

Put vibration suppression pads under the legs of your telescope or spotting scope tripod and you'll virtually end the tremors that blur your view for a few seconds each time a breeze comes up or you touch the scope to focus.

A set of three **Celestron** pads, our part #VSP, costs **$49.50.** The **Meade** #895 pads to the right cost **$49.95.** Both sets dramatically improve your observing and are well worth their low cost.

Celestron Power Tank rechargeable 12-volt batteries have the power you need to run your telescope and accessories all night long. They can be recharged hundreds of times, saving you big bucks over the cost of buying flashlight batteries every few weeks. Each has *two* 12V DC cigarette lighter outputs; 3, 6, and 9V DC outputs for accessories; an emergency spotlight; built-in recharger; shoulder strap; carry handle; and more. The 7 amp hour Power Tank shown, our part #4512V, is only **$59.95**. The 17 amp hour Power Tank, our #4517V, is sale priced at only **$89.95**.

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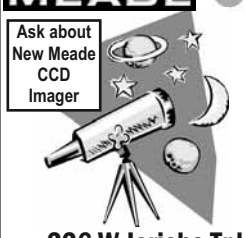

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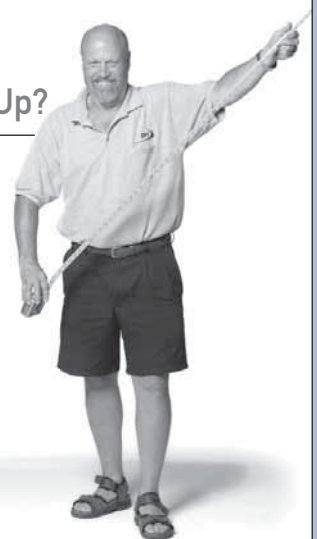

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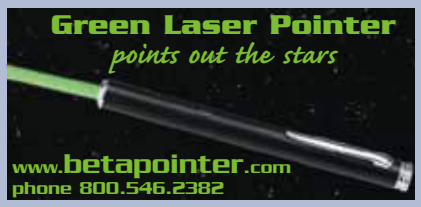
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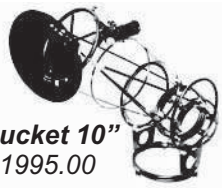
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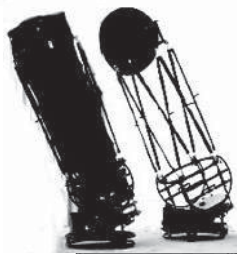

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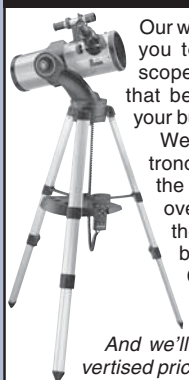
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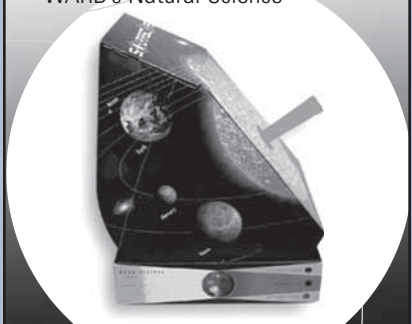

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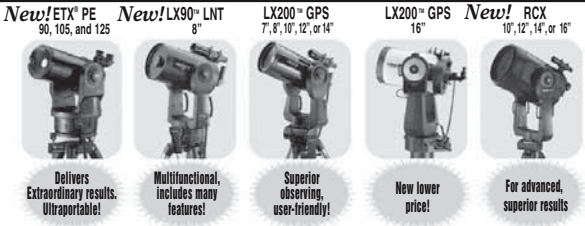

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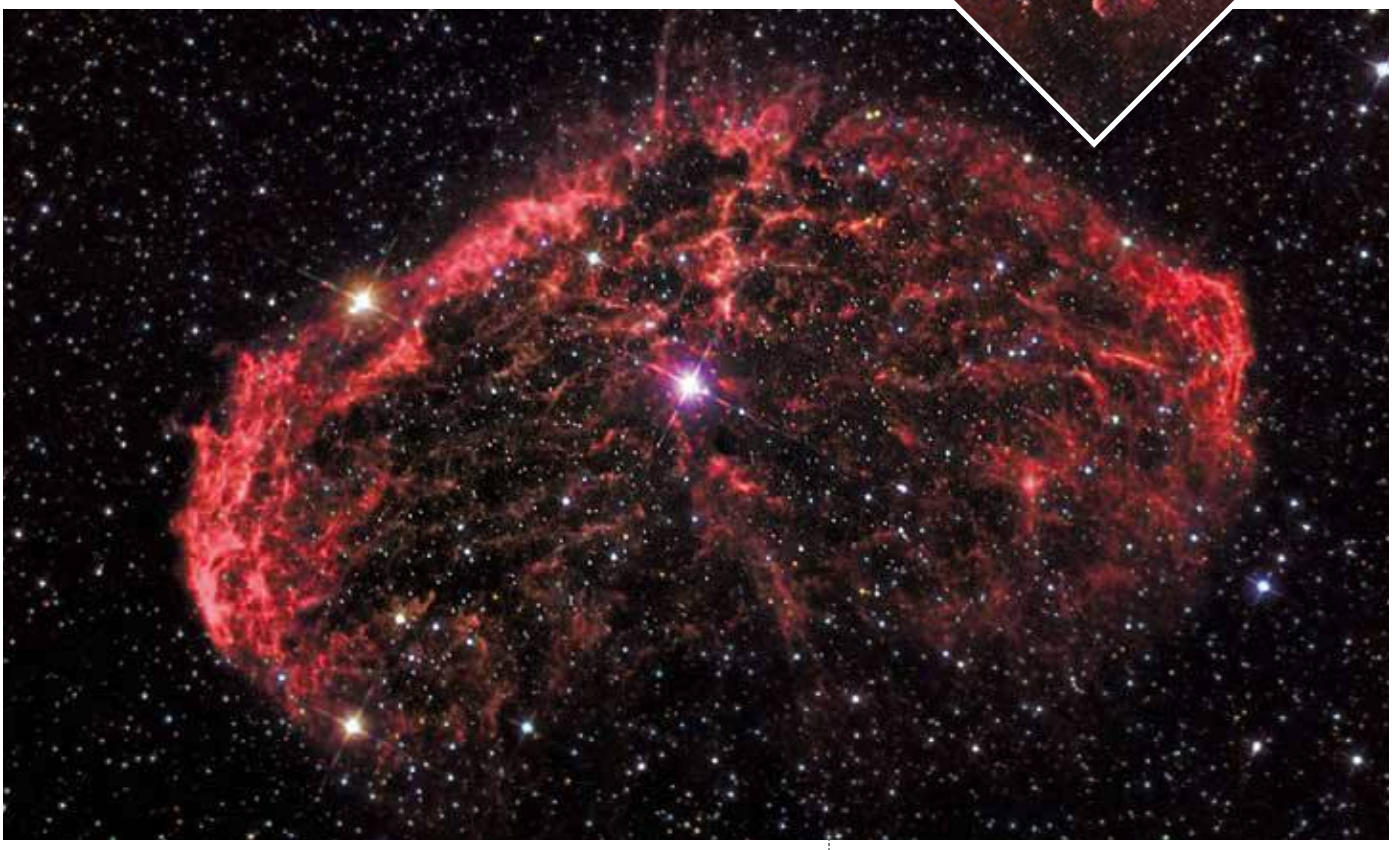
The Crescent Nebula /// IC 1848 /// ISS, Venus, and Jupiter
NGC 206 /// Saturn and moons /// M77 /// Italian sunset

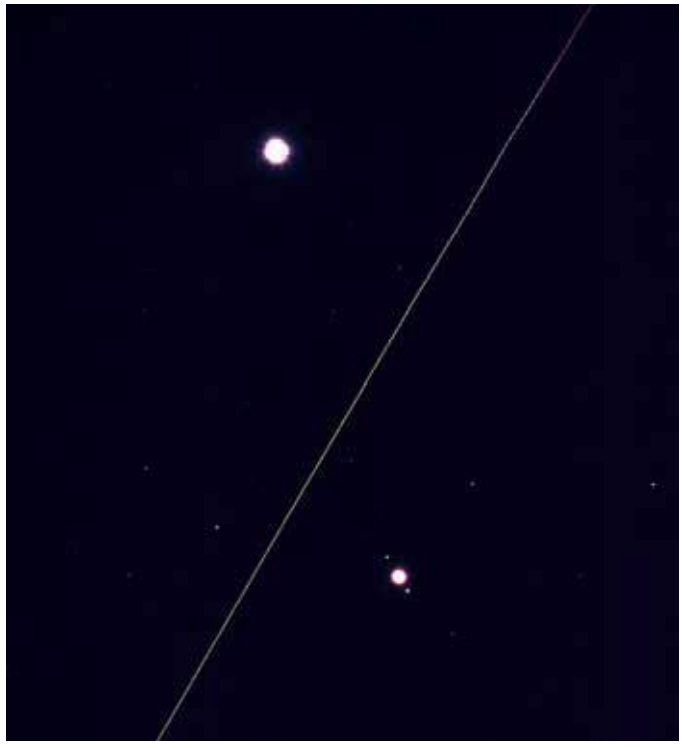


WIDE AND NARROW VIEWS OF A CELESTIAL BEAUTY

A Moon-shape nebula

The Crescent Nebula (NGC 6888) is an emission nebula that lies approximately 4,700 light-years away. In the sky, this object is located 2.4° southwest of Sadr (Gamma [γ] Cygni). At the heart of the Crescent Nebula is WR 136, a Wolf-Rayet star that emits a strong stellar wind. This wind has been compressing gas clouds near WR 136 into a crescent shape. Furthermore, the ultraviolet energy from the star excites the gas, causing it to glow. The Crescent Nebula is one of the brightest parts of the IC 1318 nebula complex, which surrounds Gamma Cygni.

THE CRESCENT NEBULA (NGC 6888) (8-inch Celestron Schmidt-Cassegrain telescope at f/6.3, Starlight Xpress SXV H9 CCD camera, Hα/RGB image with exposures of 150, 20, 20, and 20 minutes, respectively) *Inset*: **WIDE VIEW OF THE CRESCENT** (300mm lens at f/4, Starlight Xpress SXV H9 CCD camera, Hα/RGB image with exposures of 180, 15, 15, and 15 minutes, respectively) /// **WOLFGANG PROMPER**



Top left, **EMISSION NEBULA IC 1848 IN CASSIOPEIA** (6-inch Celestron C6N Newtonian telescope at f/5, Starlight Xpress SXV H9 CCD camera, Hα/RGB image with exposures of 180, 15, 15, and 15 minutes, respectively) /// **WOLFGANG PROMPER**

Top right, **THE INTERNATIONAL SPACE STATION SPLITS VENUS AND JUPITER** (3-inch Tele Vue-76 refractor at f/6.3, single-lens reflex camera, Kodak Elite Chrome 200 slide film, 20-second exposure, taken November 3, 2004, at 4:40 A.M. PST from Wildomar, California) /// **JOHN GARRETT**

Bottom, **STAR CLOUD NGC 206 IN THE ANDROMEDA GALAXY (M31)** (8-inch Celestron Schmidt-Cassegrain telescope at f/6.3, Starlight Xpress SXV H9 CCD camera, Hα/LRGB image with exposures of 20, 60, 20, 20, and 20 minutes, respectively) /// **WOLFGANG PROMPER**

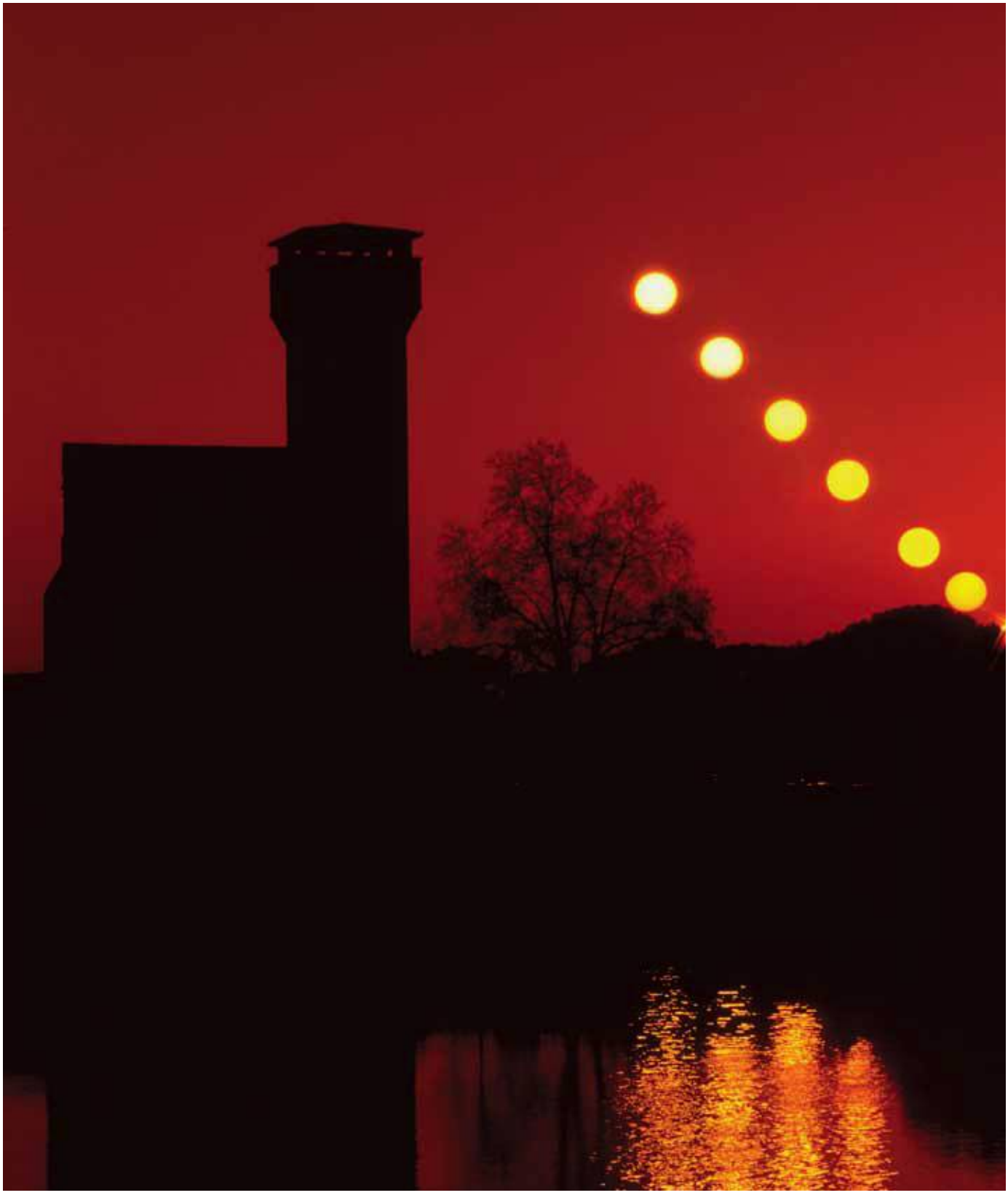
Send your photos to: ASTRONOMY reader gallery, P.O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com.
Please include your full name, date and location of image, and complete photo data: telescope, camera, film, and exposure information.

Top, **SATURN WITH (LEFT TO RIGHT) RHEA, DIONE, AND TETHYS** (10-inch Orion Optics Newtonian reflecting telescope, Philips ToUcam Pro webcam, composite of 496 1/25-second exposures, taken November 24, 2004, at 2h37m UT) /// **RALF VANDEBERGH**

Bottom left, **DARK NEBULAE B145 (TOP RIGHT) AND B146 IN CYGNUS** (4-inch Stellarvue 102EDT apochromatic refractor at f/7.8, Minolta 35mm Dimage camera, Fuji Provia 400 film, 26-minute exposure) /// **JANNE KÄLD**

Bottom right, **SPIRAL GALAXY M77 IN CETUS** (20-inch RC Optical Systems Ritchey-Chrétien telescope, SBIG ST-10XME CCD camera, LRGB image with exposures of 90, 23, 23, and 23 minutes, respectively) /// **FRANCOIS AND SHELLEY PELLETIER AND ADAM BLOCK/NOAO/AURA/NSF**

SUNSET BEHIND PISA CASTLE (Canon Elan camera, 100mm lens at f/19, Fuji Velvia 100F slide film, eight $^{1}/_{4000}$-second plus one $^{1}/_{125}$-second exposure taken April 4, 2004, from Pisa, Italy) /// **MARCO MENIERO**



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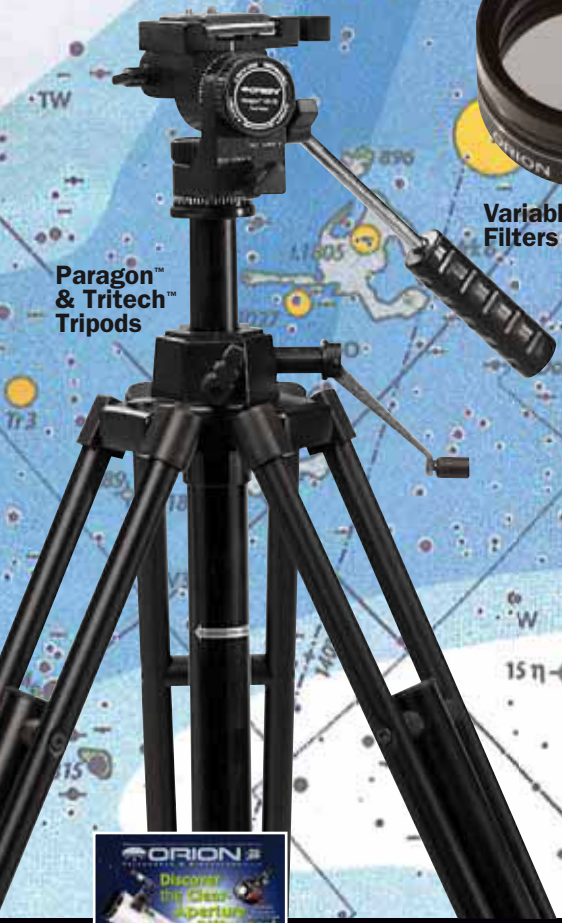

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